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THE KILN DRYING OF LUMBER

PREPARED IN THE
EXTENSION DIVISION OF
THE UNIVERSITY OF WISCONSIN

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PREFACE

In recent years interest in the kiln drying of lumber has increased notably. Manufacturers of wood products not only are anxious to improve present practices, but many of them also want to expand their kiln capacity so as to be able to season more lumber artificially. This increased interest is due chiefly to the following factors: (1) The improvement made in kiln drying practices during the last decade, together with the demonstration in various parts of the country that green lumber can be kiln dried satisfactorily; (2) the relatively high price of lumber since the World War and the consequent increased desire to reduce the amount of degrade and waste of lumber in kiln drying and to avoid long periods of air seasoning and deterioration; (3) the shipment of lumber long distances which makes it desirable to reduce the weight to a minimum; and (4) the general trend toward increasing efficiency in manufacturing lines, largely because of the high cost of labor and materials.

To meet the universal demand for kiln drying information, a correspondence-study course was prepared in the University Extension Division of the University of Wisconsin. The mimeographed text material here developed met with such favor and proved of such usable service that it is now put into printed form. The present text represents the latest revised and enlarged text material developed out of this practical inter-relationship between the authors in their laboratories and the men in the industries.

This text presents in a simple yet accurate and logical manner a working knowledge of the principles underlying the successful seasoning of lumber in kilns. A good understanding of wood and its behavior under various conditions of moisture is necessary for the operation of dry kilns. Several chapters are devoted to this subject. But the importance of keeping the drying process (temperature, humidity, and circulation) right is emphasized throughout the book, for this is the true basis of success in drying lumber.

Although the practice of artificially seasoning lumber is an old practice, relatively little has hitherto been published along these lines. Nor can a student get much accurate information from commercial practices. There is no standard method of kiln drying lumber such as there is for making cheese or smelting iron. In fact the general commercial practice of kiln drying is far inferior to what one would expect in industries as old as are many of those engaged in the manufacture of wood products.

The following pages will not only be of immediate help to the practical man whose duty it is to operate dry kilns, but it is hoped that they will arouse his interest in the subject so that he will do some intelligent experimenting on his own account. In so doing not only will he develop his efficiency but he will also change a commonplace job into an interesting and challenging vocation.

The authors acknowledge their indebtedness for much of their material and many of the illustrations to the United States Forest Service which has taken a leading part in improving the lumber practices in the interests of conservation. They are also particularly grateful to H. D. Tiemann, who has been the pioneer in this field of work, and to A. C. Knauss, L. V. Teesdale, W. K. Loughborough, and others who have made helpful suggestions and criticisms while the manuscript was in preparation.

A. K.

R. T.

MADISON, WISCONSIN,
December, 1925.

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THE KILN DRYING OF LUMBER

CHAPTER I

GENERAL

1. Purpose of Seasoning Lumber.—Seasoning means to make fit for use; seasoning lumber invariably means the removal of some of the moisture, that is, drying. With respect to some other commodities, seasoning may have a different meaning, as the seasoning of food with salt. The removal of moisture from lumber usually is accomplished by exposing the lumber to outdoor atmospheric conditions or to the higher temperatures of a dry kiln. A great deal of wood is air dried only, especially that which is used in large sizes, such as timbers, joists, and scantlings, but a considerable amount is dried in kilns.

The following are the main objects of seasoning lumber, whether by the natural elements or in an artificially heated chamber:

1. To reduce the shrinking, warping, and checking of lumber after it is put into use. Changes in dimension and shape usually are the result of changes in moisture content. If lumber is dried so that it will not change in moisture content a great deal after it is cut into finished sizes, it will retain its shape sufficiently well for almost all practical purposes.

2. To make it less subject to decay, stain, mold, and attack by insects. Decay, some kinds of stain, and mold are due to a fungous growth, which is a low form of plant life. Fungi cannot thrive unless a certain amount of moisture is present. When wood is thoroughly air dry or kiln dry, it is immune from attack by fungi and will remain so as long as it is kept in that condition.

Many insects which attack green or partly seasoned wood will not attack it when it is thoroughly dried. An exception is the powder-post beetle, which, in the course of time, reduces to dust seasoned sapwood of ash, hickory, elm, and some other hardwoods.

3. To reduce freight charges on lumber shipments. Almost all sawmill operators find it profitable to dry their lumber at least partly before it is shipped, because it is customary for the shipper to quote prices delivered. The shipping weight can be reduced by one-fourth to one-half in many cases by allowing the lumber to season. This means a considerable saving on almost any shipment of lumber, except cargo shipments which often are loaded green, because water rates commonly are based on the thousand board feet instead of on the weight of the lumber.

2. Reasons for Using Dry Kilns.—The kiln drying of lumber may be defined as the process of seasoning wood under artificially induced and controlled conditions.

There are two primary reasons for kiln drying lumber:

1. To reduce its moisture content more rapidly than can be done in air drying. When air drying would require several months or a season, kiln drying can be done in a few days or in two or three weeks. Rapid drying means a quick turnover of capital, a more flexible operation, less capital tied up in yards, and lower insurance costs and taxes.

2. To reduce the moisture content of lumber below that attainable in air drying. Whenever wood is to be used in heated buildings, or even outdoors, where tight joints are necessary under the driest conditions, as in wagon wheels, it is necessary to dry the lumber to a comparatively low moisture content, 4 to 8 per cent, so that little or no shrinkage will take place during and after manufacture, otherwise joints may open up or checks form. In countries where the buildings are not heated, kiln drying is practiced very little; for if the lumber is allowed to air dry thoroughly before manufacture, the danger of further shrinkage is greatly reduced.

A low moisture content also means lower freight charges than are customarily used in figuring the selling price of lumber, and hence an increase in the profits of a sale. The matter of underweights is very important for the shipper who has distant trade. Of course, if all lumber manufacturers in a certain region obtained certain underweights, competition would soon eliminate much of the profit from this source.

In addition to the above, there are certain other reasons for drying lumber in a kiln. They may not, however, be the principal ones. These reasons are:

1. If lumber is properly kiln dried, there is less deterioration due to stain, decay, insect attack, checking, warping, casehardening, and honeycombing *while drying* than usually occurs in air seasoning. On the other hand, if conditions are not properly regulated in a kiln, deterioration may be much greater than in air drying. For this reason there is a great deal of prejudice against any methods of hastening the drying process.

2. The high temperatures of a kiln cause much of the pitch in resinous woods, especially yellow pine and Douglas fir, to come to the surface, later to be dressed off, while that which remains in the interior is hardened. If the resin is not partly eliminated or hardened in drying, it may later exude, especially when the lumber is subjected to heat, as when it is in the sun's rays, or near a stove, furnace, radiator, or register. Such exudation causes the paint, varnish or enamel to blister or discolor, and may even cause objectionable dripping.

3. Lumber dried at a high temperature loses some of its capacity to hold moisture and under certain conditions does not shrink and swell so much as that which is dried under low temperatures; that is, the "working" is reduced.

4. Properly kiln-dried lumber causes less trouble in gluing and painting than air-dried lumber.

5. Less handling of lumber usually is required when it is kiln dried without preliminary air drying.

6. Wood-destroying and sap-stain fungi are killed by the temperatures usually maintained in kiln drying lumber. This means that the wood becomes sterilized and will decay or develop fungous stains only after conditions again become favorable for infection from without. In air-dried lumber, on the other hand, such fungi, when present, are only dormant and are ready to resume their work of destruction as soon as the lumber becomes damp.

7. Insects are killed by the temperatures ordinarily used in kiln drying lumber. This fact is important in connection with insects which work in air-dry lumber and are not destroyed in air seasoning.

3. Conditions Necessary for Kiln Drying Lumber.—In the removal of moisture from lumber two steps are involved: (1) The transfusion of moisture from within outward, and (2) the evaporation of the moisture. *Heat* hastens *both* these processes. Heat, therefore, is essential in the rapid drying

of lumber, and the hotter the temperature in a kiln the more quickly will the operation be completed, other conditions being favorable. Difficulties are apt to arise, however, when lumber is heated. If hot, dry air is used, the evaporation will take place much more rapidly than the moisture comes to the surface, so that the surface layers will become a great deal drier than the interior, and casehardening or surface checking will result. To prevent excessive surface drying, the air in the kiln must be kept moist; that is, a certain *humidity* must be maintained. In order to supply heat to the lumber and take away the excess humidity, a *circulation* of the air is necessary.

Heat, humidity, and circulation, therefore, must be properly controlled in a lumber kiln to dry the lumber rapidly, yet without injury. To control these, the kiln must be properly constructed and the lumber properly piled.

It is true that a great deal of lumber is dried satisfactorily when not much attention is given to these principles. This applies especially to softwoods and previously air-dried hardwoods. Such material can endure considerable abuse with comparatively little depreciation. The drying of green lumber or only partly air-dried material, especially hardwoods and thick softwoods, is more difficult and requires more consideration of the laws governing the evaporation and the transfusion of moisture in wood.

4. Difficulties Encountered in Kiln Drying Lumber.—In the kiln drying of lumber numerous difficulties arise, many of which are not met with in the drying of fabrics and certain other materials. Some of these difficulties can be avoided or overcome entirely, while others can be reduced to a minimum by intelligent operation of the kilns. The following are some of the principal factors which may annoy the operator and add to the discouragements incident to the insistent demands of the production or shipping departments for more or better dried lumber when he has inadequate equipment to produce it.

Shrinkage is responsible for many of the troubles encountered. The shrinkage of wood as it dries is not uniform, and thus stresses result which may cause checking, casehardening, honeycombing, and warping. It should be remembered that nature never uses wood in a dry condition; when man attempts to season it, therefore, it is not surprising if more or less trouble occurs.

A form of excessive shrinkage known as "collapse" is quite common in drying green lumber of certain species at a high temperature.

The wood may become discolored. For example, maple sapwood, some western yellow pine sapwood, and sugar pine turn brown under certain conditions.

The lumber may become moldy in a kiln if dried at a comparatively low temperature and high humidity.

The lumber may dry unevenly so that part of the kiln charge becomes dry before the rest of it is ready to be taken from the kiln.

The lumber may become too dry. Aside from the swelling that results afterward, a low moisture content is objectionable in that it makes it more difficult to work the lumber, and it has a tendency to loosen the knots and thereby lower the grade of the lumber.

Moisture passes out of wood slowly, limiting the speed at which it can be dried.

There may be various kinds of trouble with the equipment, some of the more fertile sources being lack of sufficient steam pressure, leakage of moisture through kiln walls and doors, air binding in the steam pipes, insufficient drainage of condensation from the heating coils, dripping of condensation from the ceiling, collecting of water on the floor of the kiln, automatic regulators getting out of order, and doors not closing properly.

5. Kiln Drying versus Air Drying.—In the minds of those who are not familiar with improved methods of kiln drying, this process at its best is but an inferior substitute for the process of drying lumber under ordinary atmospheric conditions. The kiln-drying process is sometimes referred to as "artificial seasoning" as contrasted with "natural seasoning," or drying lumber in the open air. Some claim that the "natural" method must undoubtedly be better than any "artificial" method in which man interferes with the processes of nature, and considerable prejudice against kiln drying exists for this reason.

A little thought will show the absurdity of such a belief. In attempting to dry lumber by artificial means, man does not interfere with the laws of nature but makes efficient use of them. Nature, when left alone, does not always do things in the best and most economical way. This is shown nowhere better than in the sowing of seed. When nature sows a hundred seeds, prob-

ably two or three mature and produce more seed. When man wants a crop, he gathers the seed in the fall and takes care of it during the winter; the next spring he prepares the ground and sows the seed; and out of a hundred seeds he probably gets ninety to produce more seed. Similar improvements are made in food and shelter. Man is not satisfied with food, as a rule, as it comes from the plant or animal, but he seasons it and cooks it so as to make it more palatable and more easily digestible. The human eye often is far from perfect, and man improves on it by the use of eyeglasses. Man constantly, in thousands of ways, improves on the natural processes, and there is no reason why he cannot do just as good or better work in drying lumber than the natural elements, by regulating conditions in a kiln so as to produce the desired results.

The relative merits of artificially seasoning lumber as compared with drying it by exposure to the natural elements, both as to the quality of the lumber and the cost of drying it, depend upon a number of considerations. Therefore, no arbitrary statement can be made in favor of the one or the other process which will hold for all conditions. Enough experimental work has been done, however, to indicate that *with proper care* all kinds of lumber can be dried in a kiln with fully as good results, as far as the quality of the lumber is concerned, as can be obtained in air drying.

In discussing the relative costs of drying lumber by these two processes two classes of lumber must be considered: (1) that for which air seasoning alone is sufficient, as rough lumber, shiplap, etc.—mostly softwoods; and (2) that which must later be kiln dried, even if previously air dried, as furniture and vehicle stock—largely hardwoods.

If it is not necessary to dry lumber to a lower moisture content than can be attained in air drying, it usually is considered less expensive to air season it than to dry it in a kiln, unless serious deterioration takes place while it is in stacks outdoors or there is immediate demand for the stock. With higher lumber prices, however, there is an increasing tendency to kiln dry all stock, especially 1-inch lumber, so as to avoid the charges accruing from air seasoning.

If the lumber must be kiln dried eventually, the entire drying from the green condition may often be done to advantage in a kiln. With hardwoods, however, the common practice is to air

season them before kiln drying, principally because green hardwoods are difficult to kiln dry without serious degrade.

Kiln drying is quicker than air seasoning, and there is the possibility of producing lumber of even better quality. On the other hand, it requires constant attention and considerable mechanical equipment.

In deciding whether it pays to kiln dry lumber instead of to air dry it, the following factors must be considered:

AIR DRYING

Interest on capital invested in ground occupied by lumber yard, yard equipment, and the large amount of lumber kept in storage.
Taxes on land and equipment.
Insurance on equipment and lumber.
Depreciation of equipment.
Depreciation of lumber while it is drying.
Cost of handling lumber from time it is received until it is ready for shipment or manufacture.

KILN DRYING

Interest on capital invested in ground occupied by kilns and trackage, dry kilns and equipment, including extra boiler capacity, storage sheds, and the small amount of lumber kept in storage.
Taxes on land, kilns, sheds, and equipment.
Insurance on buildings, equipment, and small amount of lumber.
Depreciation of buildings and equipment.
Depreciation of lumber while it is drying.
Cost of handling lumber from time it is received until it is ready for shipment or manufacture.
Cost of operation of kilns—attendance, fuel, water, etc.

As timber becomes higher priced, the air drying of lumber will become more expensive on account of the larger amount of capital required to carry the stock through the seasoning period. The cost of kiln drying, however, will not increase appreciably from this cause.

Any increase in freight rates has a tendency to encourage kiln drying because of the lower weights attainable.

The increasing cost of labor also adds to the expense of the extra handling of stock which is first air seasoned and then kiln dried.

At sawmills, planing mills, and wood-using factories, located in cities in which the value of the property is increasing from year to year, the large amount of land required to air season lumber is an important factor in increasing the use of kilns and in artifi-

cially drying more of the lumber without storage in the yard for any length of time.

6. The Need of Technical Information on Kiln Drying.—The successful drying of lumber in a kiln depends principally on a thorough knowledge of the behavior of wood under various conditions due to moisture and temperature. It is not primarily steam and ventilating engineering, although skill along these lines is important in the construction, operation, and repair of kilns.

If the drying of lumber were only a matter of evaporating moisture, as in drying clothes in a laundry, it would be a comparatively simple procedure—a good circulation of hot, dry air would do the work quickly. Various difficulties may arise, however, as has already been pointed out. A dry-kiln operator should understand wood so thoroughly that he can judge from its appearance or can make intelligent tests to determine how the stock is drying in the kiln. If anything goes wrong, he should know what changes to make so as to prevent serious injury to the lumber.

Too often the operation of a dry kiln is left to some person about the plant who has a multitude of other duties to perform. The result is that the stock is neglected and becomes depreciated and perhaps ruined. Under such conditions the fault is often laid to the time of the year when the timber was cut, or to the particular locality from which it came, or to the type of kiln in use, when in fact the loss was due to the haphazard methods by which the kiln was run.

Many failures in kiln drying are due to improperly constructed kilns; but, in general, a good operator and a poor kiln make a better combination than a poor operator and a good kiln.

Commercial kiln drying covers many different species, grades, and sizes of lumber with wide variations in moisture content. Furthermore, the purposes for which the lumber is dried are widely different, so that no simple rule of procedure can be laid down. A kiln operator has the best chances for success if he thoroughly understands the principles involved in drying lumber so that he can solve his particular problems brought about by the kind of lumber and the type of kiln with which he must work.

Enormous amounts of lumber still go to waste each year because of the inadequate methods of drying, and much of the kiln-dried lumber used is inferior in quality because it is une-

venly dried, checked, casehardened, honeycombed, or has otherwise deteriorated. Such material gives unsatisfactory service, and the builder and the manufacturer are inclined to turn to other materials, such as cement and steel, which are prepared for use on a more scientific basis.

It is estimated that about 4,725,000,000¹ board feet of hardwoods and 15,116,000,000 board feet of coniferous woods are kiln dried each year, and that the depreciation in value during previous air drying and subsequent kiln drying averages about 12 per cent for hardwoods and 8 per cent for conifers. While these losses cannot be eliminated entirely, they could probably be reduced to 2 per cent in both hardwoods and softwoods by properly kiln drying the material direct from the green condition, effecting a saving of 10 and 6 per cent, respectively. Under present prices this would mean a direct saving of \$70,000,000 or more annually.

That a large amount of this loss can actually be prevented is shown by the success attained by a skilled operator at the Rock Island Arsenal in drying green black walnut for gun stocks and heavy green oak for artillery wheels. While, by methods commonly used in commercial drying, the losses have ranged from 35 to 60 per cent for the gun stocks, and 10 to 50 per cent for the heavy oak, in this case the loss caused by kiln drying of the black walnut was *one-half* of 1 per cent and of the oak only 2 per cent.

7. The Economic Significance of Kiln Drying Lumber Properly. Considered from the standpoint of the country as a whole, the proper operation of dry kilns is of considerable economic significance. There is no question but that a large amount of the waste or degrade that now occurs in drying lumber either outdoors or in kilns can be prevented by the intelligent operation of kilns.

By drying lumber to a low moisture content at the mill, the freight charges on the lumber can be reduced considerably. It is estimated that in 1922 the country's freight bill on lumber was \$250,000,000. A reduction in weight of 2 per cent in addition to what already is accomplished would mean a saving of approximately \$5,000,000 in transportation alone. On many shipments a reduction of from 5 to 10 per cent would be within the range of practical possibilities, and occasionally a reduction of over 30 per cent could be possible. Furthermore, with reduced weights

¹ TIEMANN, H. D., "The Kiln Drying of Lumber."

more lumber could be loaded onto a car and some rolling stock released for other purposes.

The time that can be saved in cutting down the length of drying periods at some plants by remodeling the kilns, installing modern equipment, and operating the kilns so that the lumber will dry in the minimum of time without serious degrade is considerable. It is possible in some cases to increase the kiln capacity over 25 per cent by merely improving present practices. On the other hand, many manufacturers try to dry lumber in so short a time as to make good results impossible. One manufacturer found that by lengthening the drying time of each charge the degrade was greatly reduced. As a result, he did not need to dry anywhere near so great a quantity as before, and his kilns which previously were crowded afforded ample capacity.

Wood dried uniformly, to the right moisture content, and without serious internal stresses, will give more satisfaction while passing through the shop, and in the finished product, than when improperly dried. Lumber satisfactorily dried means less culls in the shop, fewer replacements, less return of goods for repair or adjustment, and a better reputation for the manufacturer or builder than lumber dried in a haphazard way. Examples of lumber, small dimension stock, or finished sizes, warping, checking, or shrinking to undersize while passing through the shop are common. The checking of wooden products, the opening up of joints, and the misfit of drawers or doors after they leave the factory are fruitful sources of complaint which can often be traced back to the kiln. Any elimination of waste, whether of time, money, or materials, means cheaper production and lower selling prices, which are essentials in improving the economic condition of a country.

A reduction in degrade and waste of lumber means that less lumber needs to be cut, furnishing one of the means of prolonging the rapidly diminishing supply of timber. Furthermore, most of the 20,000,000,000 feet of lumber that are kiln dried each year consists of the upper grades. If the degrade caused by seasoning the upper grades could be reduced to 2 per cent, not only would less high-grade lumber need to be cut but some of the lower grades that are the natural accompaniment of high-grade lumber and much of the low grade produced by improper kiln drying would not be thrown on a market already flooded with low-grade lumber. This would afford the lumberman a better

opportunity to dispose of the legitimate lower grades and hence encourage closer utilization.

The timber in this country is now being cut four times as fast as it grows. Any reduction of the drain on the forests, especially when it can be accomplished without curtailing the industries, is a step toward the efficient conservation of one of the most important natural resources.

CHAPTER II

THE STRUCTURE OF WOOD IN RELATION TO ITS DRYING

8. Cellular Structure of Wood.—In order to be able to identify the different species of wood and to distinguish plain-sawed lumber from quarter-sawed lumber, to understand better how the moisture is held in wood and how it comes out, and how shrinking, checking, warping, casehardening, and honeycombing take place, it is necessary to know something about the minute structure of wood. Wood is composed of cells. Each cell has a cavity and a wall similar to the cells of a honey-comb, but the cells in wood are much smaller and more irregular in size. Many of these cells are comparatively long for their diameter and for that reason are called *fibers* (see Fig. 1). These fibers, which usually comprise the bulk of the wood, extend vertically in the tree and are the elements which give strength to the tree trunk. They usually are from $\frac{1}{25}$ to $\frac{1}{4}$ inch in length and are closed at both ends. They grow together with practically no space between them (see Fig. 2).

9. Pores in Hardwoods.—In the hardwoods, and these include all native trees with broad leaves, there are scattered among the fibers larger cells with open ends set one above the other like tile in a chimney. These cells form continuous ducts which serve to conduct sap in the living tree and are called *pores* or *vessels*. Figure 1 shows a side view and Fig. 2 a cross-section of pores. In some woods, such as oak, ash, chestnut, and walnut, these pores are large enough to be seen, without magnification, on smoothly cut surfaces. On the end grain they appear as minute holes, and on the side grain as fine grooves, which require a filler in wood finishing. In some other hardwoods, such as basswood, maple, the gums, and yellow poplar, the pores cannot be seen without the aid of a magnifying glass.

In some hardwoods the pores of the heartwood and even of the inner sapwood are filled with froth-like growths known as *tyloses*, leaving only the pores of the outer sapwood open to con-

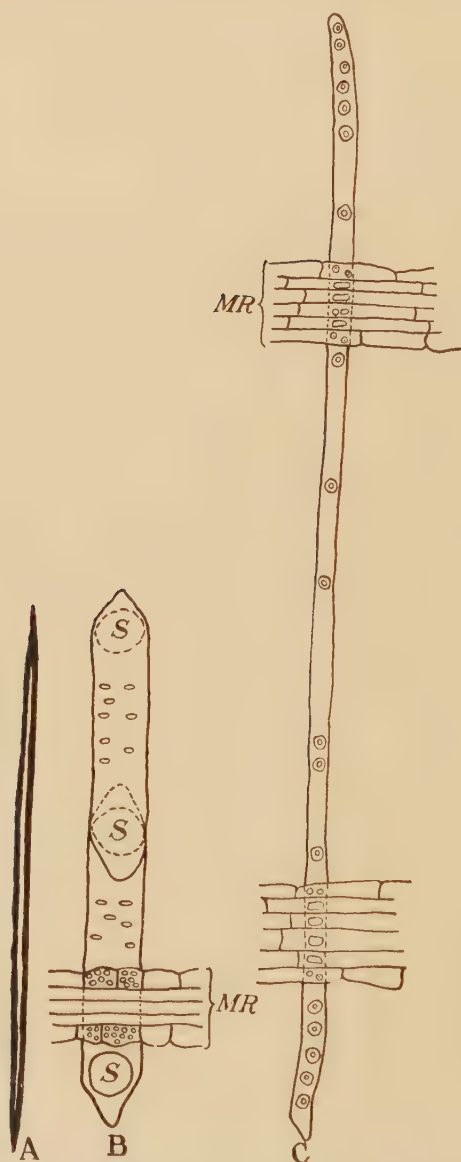


FIG. 1.—Wood elements.

A, a hardwood fiber; *B*, two vessels (pores) of a hardwood with ends adjoining, showing perforations, *S*, through which sap passes; *C*, a coniferous fiber; *MR*, medullary ray cells. The small circles and ovals are thin places in the cell walls ("pits") through which the sap passes to adjoining cells when there is no direct opening.

duct moisture to the leaves (see Fig. 2). Tyloses are an ingrowth of the surrounding cells into the vessels. If they serve the tree any purpose, the purpose is unknown. The tyloses in the pores do not interfere appreciably with the drying of the wood.

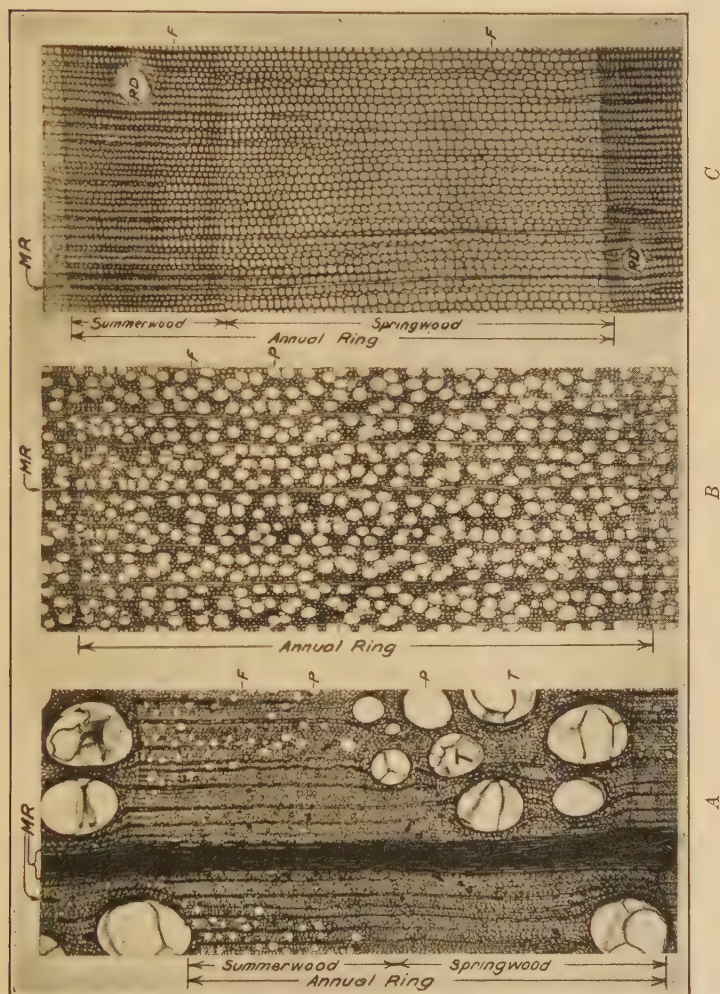


Fig. 2.—Photographs of thin cross-sections of wood magnified about 25 diameters.
A, white oak; B, red gum; C, shortleaf pine. P, pores; T, tyloses; F, fibers; MR, medullary rays; RD, resin ducts.

For instance, in the woods of the white-oak group the pores are almost completely plugged up with tyloses, yet these woods dry at about the same rate as the woods of the red-oak group in which tyloses are so rare that it is possible to blow through a stick several feet long.

10. Absence of Pores in Softwoods.—In the softwoods, or conifers, that is, trees with needle- or scale-like leaves, the fibers (called “tracheids” in conifers) serve the combined purpose of conducting sap and giving strength to the tree; there are no specialized pores¹ for conducting sap. (See Fig. 1, and compare the pine with the oak and the gum in Fig. 2.) Since these fibers are closed at the ends and are rarely over $\frac{1}{4}$ inch in length, it would seem that the conifers would be handicapped in conducting sap to the leaves, or that the wood of coniferous species would dry out more slowly than do hardwoods, which have continuous pores, yet such is not the case. The tallest trees are conifers, and, as a class, the conifers season more easily than the hardwoods.

11. The Medullary Rays.—In all trees, except palms, yuccas, and bamboos, there are strips of cells running across the grain in a radial direction into the bark. They are known as *medullary rays*, or simply *rays*, and are illustrated in Figs. 1, 2, and 5. Their purpose is to conduct sap across the fibers from the bark to the sapwood, or *vice versa*. These rays are largest in oak, where they appear as distinct lines on the end grain and as “flakes” or “silver grain” up to 4 inches in height on quarter-sawed faces. In other woods, even in the softwoods, they can be seen on split radial surfaces as fine strips running across the grain. Although they are very small in almost all woods, they are very numerous. On the flat grain surface of yellow pine, for example, about 15,000 rays occur per square inch. These rays play an important part in the drying, shrinking, and checking of wood.

12. The Springwood and Summerwood of the Annual Rings.—Trees, unlike animals, do not grow throughout their entire body, but increase in size by the addition of new tissues immediately underneath the bark and at the tips of the main shoot, branches, and roots. The wood formed in any season ripens that same year and does not change appreciably thereafter, except that the sapwood turns to heartwood. Therefore, it makes no difference, as far as the wood itself is concerned (except the outermost annual ring), at what time of the year it is cut.

In temperate climates in the spring of each year new cells begin to grow on the outside of the wood previously formed. In many woods these cells are comparatively large, making a layer of soft,

¹ The word “pores” is here used in a technical sense. All woods are porous in the sense that they contain hollow cells, and absorb water.

and, especially in the conifers, lighter-colored wood known as *springwood*. As the season advances, the trees seem to lose some of their vigor, and smaller cells, usually with thicker walls, are produced, adding a denser layer known as *summerwood* on the outside of the springwood. This growth is illustrated in the cross-sections in Fig. 2. The summerwood may be very pronounced, as in the yellow pines, Douglas fir, oak, ash, and chestnut. In other woods, such as the white pines, the gums, maples, birches, and yellow poplar there is little difference between springwood and summerwood. Springwood and summerwood together constitute a year's growth and make an *annual ring*. Many trees of the tropics, which grow all year long, do not produce well-defined annual rings.¹

13. Quarter-sawed and Plain-sawed Lumber.—Because of the presence of medullary rays and annual rings in wood it may be cut into lumber in two distinct ways: It may be cut parallel with the rays, across the rings, that is, from the bark toward the center, producing what is known as radially cut, quarter-sawed,

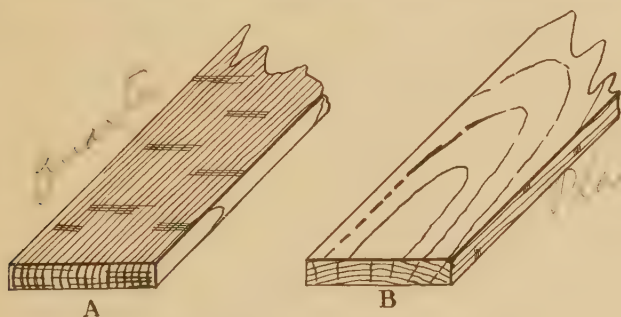


FIG. 3.—Two ways of cutting lumber from a log.

A, quarter-sawed, or edge-grain board. B, plain sawed, or flat-grain board.

or edge-grain lumber; or it may be cut more or less at right angles to the rays or tangent to the rings, producing tangentially cut, plain sawed, or flat-grain lumber. Boards cut in these two ways are illustrated in Fig. 3.

Plain-sawed lumber dries more rapidly than quarter-sawed lumber under the same conditions because the medullary rays, the purpose of which is to conduct moisture, or sap, across the grain, come out in great numbers on the broad tangential faces,

¹ The annual rings are often referred to as being the "grain" of wood, but this meaning is not strictly adhered to, for it must be conceded that tropical woods without annual rings also have grain.

while in quarter-sawed lumber they run more or less parallel to the faces and do not bring much moisture to the surface. On the other hand, plain-sawed lumber gives more trouble in drying because of its tendency to check and cup.

For many purposes, quarter-sawed lumber is preferable, but occasionally plain-sawed lumber is more desirable. The following are the principal advantages of quarter-sawed, or edge-grain, lumber:

1. It shrinks less in width.
2. It twists and cups less.
3. In many species, as in oak, sycamore, and mahogany, it is more beautiful.
4. It wears more evenly, and does not sliver up so much.
5. It does not caseharden, surface check, or split open so badly, and, therefore, it can be dried more rapidly by subjecting it to more severe drying conditions.

The following are the principal advantages of plain-sawed, or flat-grain, lumber:

1. It is cheaper to cut at the mill.
2. In some species, as in yellow pine, cypress, Douglas fir, ash, and elm, it gives a more beautiful figure.
3. Wider sapwood boards can be cut than in quarter sawing—when this is desirable.
4. If knots are present, they are round knots instead of spike knots, as in quarter-sawed boards.
5. It does not collapse¹ so easily in drying.

14. Heartwood and Sapwood.—Young wood is always light colored, but as a tree becomes older the portion near the center, which is the oldest, turns darker in most woods, producing *heartwood*, as it is called, in contradistinction to the outer portion which is called *sapwood*.

In a few woods, for example, spruce (except Sitka spruce), hemlock, true fir, cottonwood, and basswood, the heartwood and the sapwood are of about the same color, especially after the lumber is dry.

The width of the sapwood depends upon the kind of wood, the conditions under which the tree has grown, and the height from the stump. In northern white cedar, chestnut, black ash, black locust, and others the sapwood usually is less than an inch in thickness, while in loblolly pine, western yellow pine, red gum,

¹ Explained in chap. IV.

maple, white ash, and hickory the sapwood is usually several inches thick. Trees grown in the open under favorable conditions have more sapwood than the same species grown in a crowded forest. The sapwood is widest at the stump and becomes narrower toward the top of the tree trunk.¹

The change from sapwood to heartwood is due to an infiltration of slight amounts of various substances, as gums, resins, and tannins, but it is not accompanied by any appreciable increase in weight or strength.

Heartwood has the following advantages as compared with sapwood:

1. It usually is more ornamental.
2. It nearly always is more resistant to decay and stain-producing fungi, and attack by certain insects.
3. It is less permeable to liquids—of importance in cooperage and tanks.
4. It often is lighter in weight when green because in many species it has a lower moisture content.

Sapwood has the following advantages:

1. Occasionally it is more desirable because it is white; for example, for yellow pine interior finish, maple flooring, and ash and hickory handles.
2. It dries out more rapidly than heartwood of the same moisture content. For some undetermined reason, liquids pass through sapwood more easily than through heartwood, whether coming out or going in.
3. It produces clearer grades of lumber because it is the outer, less defective, portion of the tree.
4. In resinous species it is not so likely to exude pitch as is the heartwood because it contains less pitch.

15. Structure of the Cell Walls.—For a clearer understanding of how moisture is held in wood and how it transfuses to the surface, it is necessary to go into the structure in even greater detail than can be done with the microscope. The following

¹ For further details as to the structure of the principal native trees see: ROTH, FILIBERT, "Timber," *Forestry Bull.* 10 and KOEHLER, ARTHUR, "Guidebook for the Identification of Woods Used for Ties and Timbers," *Miscellaneous Forestry Bull.* The latter bulletin also contains maps showing where the principal species grow. These publications may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C.

description of the structure of cell walls is only a theory, but the theory is borne out by closely related facts.

The walls of wood cells are believed to be made up of exceedingly fine particles or threads which extend in the wall in a spiral direction, as illustrated in Fig 4. These threads are known as *fibrils*. That cell walls have a spiral structure is not a theory since with a microscope fine spiral striations can be seen in the cell walls; and when the cell walls split or check, the splits can be seen to extend in a spiral direction. The individual fibrils, however, are too small to be seen even with the highest-powered microscope.

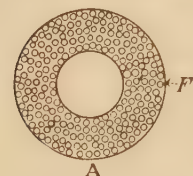


FIG. 4.—Theoretical structure of a cell wall, showing the spiral arrangement of the fibrils *F*.

A, Cross-section; B, side view.

These fibrils are believed to be exceedingly numerous and so close together in normal wood that they have a strong mutual attraction for each other, considerable force being required to separate them completely, as in breaking or splitting wood. In moist wood, however, the fibrils are slightly separated by the water contained in the cell walls, as these fibrils apparently have a greater affinity for a certain amount of water than they have for each other. Hence, the strong tendency of dry wood to absorb moisture, and the reluctance with which wood gives off moisture.¹

As moisture leaves the cell walls the film of water between the fibrils becomes thinner, the fibrils draw closer together, and the wood shrinks as a whole. The absorption of moisture causes the fibrils to separate somewhat, and the wood to swell.

The following three theories have been advanced as to why there is a limit to the extent to which wood swells:

1. As the distance between the fibrils increases on account of the absorption of water by the cell walls, the force of attraction of the fibrils for each other and for additional water decreases.

¹ It has been found that dry wood has such a great affinity for water that heat is evolved as the moisture is absorbed. This is known as the "heat of absorption" and has been found to vary with different kinds of woods ranging, in the woods experimented with, from 11.54 calories per gram of red-oak sapwood to 19.64 calories per gram of maple heartwood.

But the attraction for moisture decreases more rapidly than the attraction of the fibrils for each other so that a balance is established, and the limit of absorption and swelling is reached.

2. The water "dissolves" in the wood until the "solution" reaches saturation, when no more water can be taken up by the cell walls, although the cell cavities may become filled up by capillary flow of water.

3. It is very probable that the fibrils are not entirely separated from each other, like the fibers in a cotton twine, but are intergrown to some extent, forming somewhat of a network. Because of this intergrowth there is a limit to the amount of moisture wood can absorb. Whether the fibrils themselves absorb any moisture is doubtful. If they do, it probably is only a comparatively small amount.

It often happens in the drying of lumber that some of the fibrils actually separate from each other, causing spiral checks, visible with a microscope, in the cell walls. These checks, as will be seen later, may interfere with the transfusion of moisture across the grain.

16. How the Moisture Leaves Wood.—The moisture in wood is held principally in two ways: (1) that which is contained in the otherwise practically empty cell cavities; and (2) that which is absorbed by the cell walls. A small quantity of moisture is also found in the protoplasm of the living cells of the sapwood, but these live cells are very few, most of the cells in the sapwood and all of the cells in the heartwood being dead, empty cases, serving only to conduct sap or to give strength to the tree trunk.

When wood dries out, the moisture first leaves the cell cavities; after they are empty, the cell walls begin to dry out. This can be understood more easily by imagining a cell to be a leather bag partly filled with water. Under these conditions, the bag itself would be soaked with water, and it could not become dry until all the water had been removed from the inside.

The only way the moisture can come to the surface in any quantity from the interior of wood is along the cell walls. It does not flow out of the pores to the surface, nor does it seem probable that it evaporates on the interior and passes out in the form of vapor to any great extent.¹ In fact, the pores have

¹ Another theory is that the moisture in the cell wall, after the cell cavity is empty, evaporates from the wetter side of the cell and condenses on the drier side, and so on until it comes to the surface. Possibly some moisture

very little to do with the drying. In the first place, the pores open mostly on the end surface only (except in cross-grained lumber, in which many open on the sides), while drying takes place principally from the sides. In the second place, since in some hardwoods the pores are closed up with tyloses, and as all conifers have no continuous pores, the only way for the moisture to come out of such woods is by making its way along the cell walls as liquids travel along a wick. That the pores have very little to do with the drying except in "short-grained" pieces is

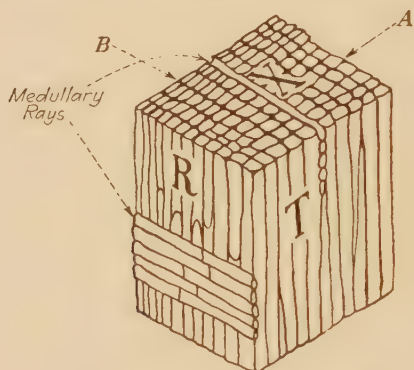


FIG. 5.—Diagrammatic drawing of a block of wood showing cross (*X*), radial (*R*), and tangential (*T*) surfaces. Arrows *A* and *B* indicate the direction in which moisture passes to the radial and tangential surfaces respectively.

shown by the fact that the white oaks, in which the pores are mostly closed with tyloses, dry practically as rapidly as the red oaks in which the pores are mostly open.

The fact that almost all of the moisture must come out across the grain to be evaporated is an important point to remember, as it will help in an understanding of some of the drying difficulties.

The end grain of wood loses moisture more rapidly than the side grain and the tangential face more rapidly than the radial face. This is due to the following reasons:

1. In traveling toward the end grain, there are more cell walls along which the moisture can travel, as shown in Fig. 5. Moisture passing toward *X* (end grain) can pass along any of

leaves wood in this manner, but it does not seem to be the principal means of transfusion of moisture, otherwise checks and dry surface layers would not hinder the transfusion but rather would facilitate it.

the cell walls except the horizontal walls of the medullary rays to come to the surface, but in passing toward *R* (radial surface) it can pass only along those walls which extend toward *R*, as indicated by the arrow marked *A*. In passing toward *T* (tangential surface), the moisture can pass only along those cell walls which lie in a plane parallel to the arrow marked *B*, including the medullary rays. Thus it can be seen that, while practically all the cell walls are available for conducting moisture toward the end grain, only about half of them can conduct moisture across the grain to the sides.

2. Moisture apparently travels along the cell walls more easily in the direction of the length of the fibers than in the direction at right angles to the fibers. For this reason, the moisture will come to the end surfaces more rapidly than to the longitudinal surfaces. It also will travel to the tangential faces more rapidly than to the radial faces because in going to the tangential faces some of it can travel along the length of the medullary ray cells, while in going to the radial faces all of it must travel across the vertical cell walls. Consequently, because of the larger amount of tangential surface exposed in plain-sawed lumber, it dries more rapidly than quarter-sawed lumber under the same conditions.¹

¹ Since the above was written, evidence has been developed at the Forest Products Laboratory to the effect that a considerable amount of moisture may evaporate in the interior of a piece of wood and pass as vapor to the surface through the cell cavities and minute openings in the cell walls.

CHAPTER III

THE "SAP," OR MOISTURE CONTENT, OF WOOD

17. Moisture, a Natural Associate of Wood.—Wood, under ordinary conditions, contains more or less moisture. The growth of wood cells takes place in those parts of the trees which are well supplied with water, and during the green condition of the cells they continue to be comparatively wet. Water, therefore, is a natural associate of wood; in fact, the two have an affinity for each other and are not easily separated.

The main object of kiln drying is to remove a part of the moisture in wood through the energy of heat, which produces evaporation. The amount of moisture retained in kiln-dried wood depends upon the purpose for which it is to be used and the care with which it is dried.

18. What Is Meant by "Sap."—The natural water in green wood is commonly referred to as "sap." Sap is not pure water; it holds in solution slight amounts of mineral matter brought up from the soil, and organic materials manufactured within the tree (principally in the leaves) from the water drawn from the soil and carbon dioxide derived from the air. In the sapwood the materials dissolved in the sap are mostly sugars; while in the heartwood there are tannins, coloring matter, and other materials varying in kind and amount with the species. Thus, there is a decided difference between the composition of the sap in the sapwood and of that in the heartwood,¹ but in either case the amount of soluble material is comparatively small, the sap being mostly water.

The results of experiments made at the Forest Products Laboratory on the amount of cold-water-soluble materials in certain woods are given in Table I.

¹ In one sense "sap" refers only to the water solution in the sapwood and inner bark, but in another sense it includes all the moisture in the tree. The term is used very loosely and has no definite meaning.

TABLE I.—PERCENTAGE OF WOOD SAWDUST SOLUBLE IN COLD WATER

SPECIES	AVERAGE PERCENTAGE BASED ON DRY WEIGHT OF THE WOOD
Longleaf pine.....	6.20
Douglas fir.....	3.54
Western larch.....	10.61
White spruce.....	1.12
Basswood.....	2.12
Yellow birch.....	2.67
Sugar maple.....	2.65
Western white pine.....	3.16
Western yellow pine.....	4.09
Incense cedar.....	3.64
Redwood.....	7.36
Mesquite.....	12.62
Balsa.....	1.77
Shellbark hickory.....	4.78

These determinations were made on fine sawdust; on larger pieces the yields would undoubtedly be less. They were made on both sapwood and heartwood in the proportions found in the tree. Sugar maple sap as it comes from the tree in the early spring contains about 4 per cent sugar, but at other seasons of the year it contains much less.

The extent to which the water in wood influences the properties of the wood is known fairly definitely, but the influence of the soluble materials on the wood is not so well known. If they do affect the wood, nothing can be done about it, as there is no practical way of removing them from lumber of the sizes used commercially. In drying lumber, the moisture is removed, but the soluble materials are not.¹

It is claimed that wood which has been in water for a long time (several years) dries more rapidly than green wood. If this is true, it probably is due to the leaching out of some of the soluble materials which, in green wood, probably have a tendency to hold the water in the wood. However, tests on the air seasoning of loblolly pine cross-arms soaked in water for thirty days showed that immersion for this length of time had no effect on the rate of seasoning.

19. How the Moisture Content of Lumber Is Determined and Expressed.—Many of the difficulties encountered in the manufacture and use of wood are due to improper seasoning. Infor-

¹ In addition to the moisture small quantities of volatile oils and acids are removed from some woods.

mation on how to determine accurately the moisture content of lumber, therefore, is very important for the woodworker. The following directions give the steps necessary in determining the moisture content of wood:

1. From the lot of which the moisture content is to be determined select what appear to be representative pieces, that is, pieces which have, according to weight and appearance, about the average moisture content. Enough pieces should be taken from each lot or shipment so that a fair average may be obtained—about one piece from every 100 to 500 pieces. In some cases it is also desirable to select some of what appear to be the wettest and some of the driest pieces so as to obtain some idea of the extremes in moisture content. Care should be taken to obtain a fair representation of both sapwood and heartwood since in green lumber the sapwood often contains more moisture while in partly dried material the heartwood may contain more moisture.

2. Cut from one end of each piece of lumber any convenient length over 2 feet. Tests made at the very ends are not accurate because they usually are either wetter or drier than the bulk of the lumber. Pieces less than 4 feet in length should be cut through the middle. These cuts should not be made through knots, rot, pitch streaks, or other abnormalities in which the moisture content may not be typical.

3. From the ends thus freshly exposed cut off a section $\frac{3}{4}$ to 1 inch thick, as in Fig. 6, or preferably several sections $\frac{1}{4}$ to $\frac{1}{2}$ inch thick. If the average moisture content is to be determined, leave the section entire; but if the distribution of the moisture within the piece is to be determined, cut the section into strips, or preferably L's, so that there will be a minimum number of pieces, as in Fig. 6B and C.

4. Trim off all loose slivers from the sections.

5. Weigh the sections immediately to an accuracy of one-tenth of 1 per cent. This weight is called the *original weight*. If a delicate scale is not available, use a larger number of sections from each piece, but do not cut them more than an inch wide with the grain or they will dry out too slowly. If the sections cannot be weighed immediately, they should be wrapped in oil paper, oil cloth, or in a damp rag if the wood is moist, or placed in a small receptacle with a tight lid until they can be weighed.

6. Put the sections in an oven heated to 212°F. , and allow them to remain there until a constant weigh is obtained. This can be determined by frequent weighings. The time required for this depends upon the thickness of the sections, the moisture content of the wood, and the kind of wood. Overnight is usually long enough for pieces measuring $\frac{1}{4}$ to $\frac{1}{2}$ inch with the grain, although dense, wet sections fully an inch wide with the grain may require a longer period of time. Very thin sections can be dried out in a few hours.

7. When the samples have reached a constant weight, remove them from the oven and immediately weigh them to an accuracy of one-tenth of 1 per cent. This weight is called the *oven-dry*

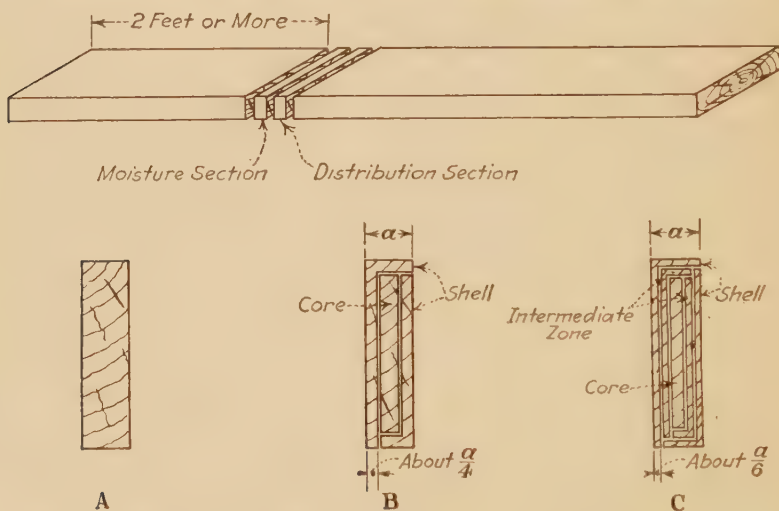


FIG. 6.—How to cut moisture test sections. A, whole piece for determining average moisture content; B, core and shell; C, core, intermediate zone, and shell for determining moisture distribution.

weight. If the sections are allowed to remain outside of the oven for any length of time, they will take up moisture from the air. It is necessary, therefore, that the weighing be done while the sections are still hot.

8. Subtract the oven-dry weight from the original weight. The difference indicates the amount of moisture lost in ounces, grams, or whatever units were used.

9. Divide the difference by the oven-dry weight and multiply by 100. This gives the percentage of moisture in terms of the oven-dry weight and should be stated as such.

Formula:

$$\frac{\text{original weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100 = \text{percentage of moisture based on oven-dry weight.}$$

Dividing the difference between the oven-dry weight and the original weight by the original weight and multiplying by 100 gives the percentage of moisture in terms of the original weight, an entirely different but not necessarily incorrect result. Hence, it is necessary to state on what the percentage of moisture is based. In this text the moisture content is always expressed in terms of the oven-dry weight, unless otherwise stated. Table II gives a comparison of moisture contents calculated by the two methods:

TABLE II.—COMPARISON OF MOISTURE CONTENTS BASED ON THE OVEN-DRY WEIGHT AND ON THE ORIGINAL WEIGHT

PERCENTAGE BASED ON OVEN-DRY WEIGHT		PERCENTAGE BASED ON ORIGINAL WEIGHT
300	=	75
200	=	66⅔
100	=	50
50	=	33⅓
25	=	20
10	=	9.09
5	=	4.76
0	=	0

For converting the percentage of moisture based on the original weight to the percentage of moisture based on the oven-dry weight, use the following formula:

$$\frac{\text{percentage of moisture based on original weight}}{100 - \text{percentage of moisture based on original weight}} \times 100 = \text{percentage of moisture based on oven-dry weight.}$$

For converting the percentage of moisture based on the oven-dry weight to the percentage of moisture based on the original weight, use the following formula:

$$\frac{\text{percentage of moisture based on oven-dry weight}}{100 + \text{percentage of moisture based on oven-dry weight}} \times 100 = \text{percentage of moisture based on original weight.}$$

Percentages based on the oven-dry weight have the distinct advantage that direct comparisons between them can be made. For example, a piece of wood having 25 per cent moisture based on the oven-dry weight has just one-half as much moisture as it had at 50 per cent; but, based on the original weight, a piece

with 25 per cent moisture has one-third as much as it had at 50 per cent. In commercial practice the percentage of moisture in lumber usually is based on the oven-dry weight. Moisture

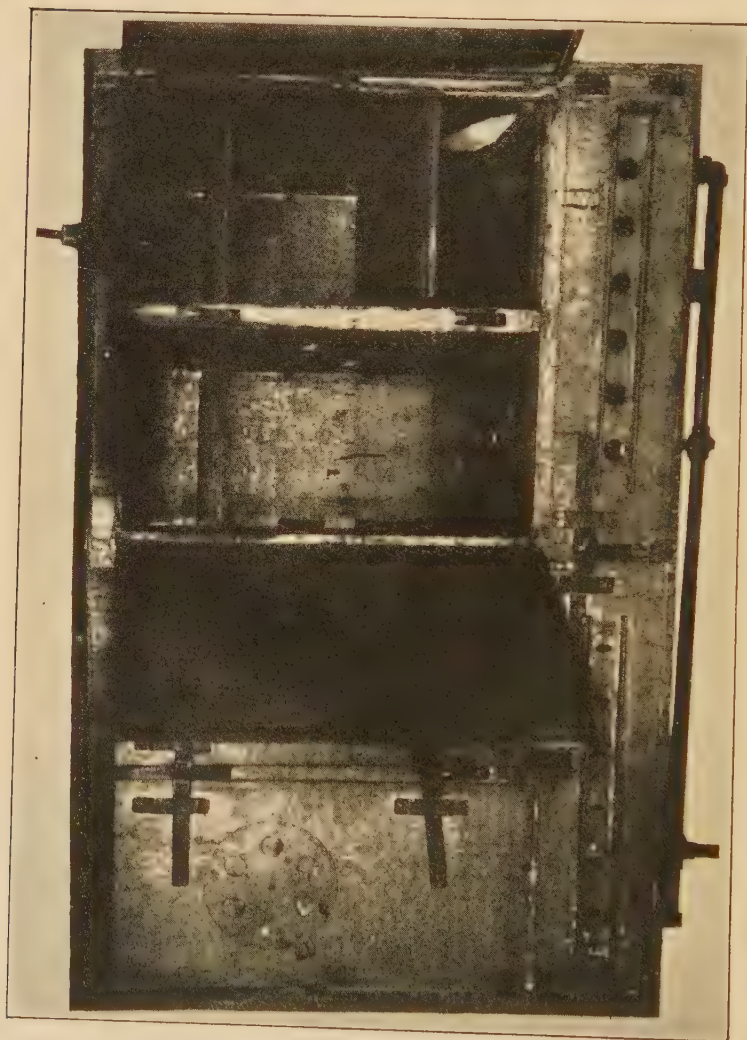


FIG. 7.—Steam-heated, sheet-iron oven for drying large numbers of moisture-test sections.

determinations made by heating resinous woods, or other woods containing volatile oils, will not be correct because of the turpentine or oil driven off with the water when the wood is heated.

Unless the wood is very resinous, such determinations will, however, be sufficiently accurate for almost all practical purposes. In an experimental kiln run made with red cedar (*Juniperus virginiana*) at the Forest Products Laboratory the oil given off in drying green heartwood sections averaged between 2 and 3 per cent, and the maximum was 4.85 per cent.

Since the moisture content is based on the weight of the wood, light woods may contain a much larger percentage of moisture than heavy woods. Wood weighing 96 pounds per cubic foot (actually such wood does not exist) could contain no water since that is the weight of a cubic foot of dry wood substance, and any water taken up by it would swell it and make it lighter per cubic foot because water is lighter than wood substance.¹

20. Equipment for Determining Moisture Content.—Ovens for drying moisture-test sections may be steam heated, water heated, or electrically heated. Some steam-heated ovens are constructed so as to have a chamber of the proper size, surrounded by a jacket on the sides, back, top, and bottom, leaving about 1 to 2 inches of space between the chamber and the jacket. The front should be equipped with a double-walled or asbestos-lined door. Steam at a slight pressure above atmosphere is admitted into the bottom of the jacket, and provision is made for draining off the condensation. Other steam-heated ovens are equipped with a coil of pipe into which steam is admitted. By means of vents in the top of the chamber the temperature in these ovens can be regulated within reasonable limits. Figure 7 shows a large oven of this type.

A water-jacketed oven can be made in a somewhat similar manner, the water in the jacket being kept at the boiling point by means of live steam pipes or a gas burner. Provision must be made for the escape of any steam which is generated. This type of oven has the advantage that it maintains a more even temperature than the steam-jacketed oven, but it is more cumbersome to operate, a factor which is a serious drawback in this kind of work.

An electric oven is probably the best when the number of sections dried is not very large. Such ovens are automatically controlled so that the temperature does not fluctuate a great

¹ Wood substance, or the material of which wood cell walls are made, has practically the same weight in all species. It is 1.54 times as heavy as an equal volume of water.

deal. They can be obtained from dealers in scientific instruments. Small ovens of this type may be made with a few electric light bulbs mounted in a sheet-iron insulated box. Figure 8 illustrates a portable oven of this type.

A drying oven should have an opening in the top through which a thermometer may be inserted so that the temperature of the air surrounding the sections may be determined.

If an oven is not available, it often is possible to dry the test sections sufficiently by placing them on a wire rack over live steam pipes or on a hot radiator. The sections should not be put in direct contact with pipes containing high-pressure steam,

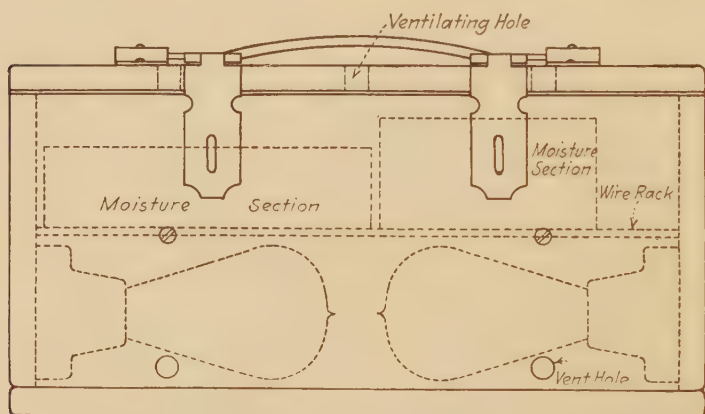


FIG. 8.—Portable electric drying oven. (Designed at Forest Products Laboratory.)

or gas or electric hot plates, since these are likely to scorch and decompose the wood.

Scales for weighing the test sections should have a capacity of 200 to 1,000 grams, the capacity depending upon the character of the work being done. Since it is desirable to weigh sections to an accuracy of one-tenth of 1 per cent, the scales should be accurate to $\frac{1}{100}$ gram so as to be satisfactory for small wood specimens. A decimal system of weights is desirable because it obviates the use of fractions. Scales weighing in grams are readily obtained from laboratory supply houses or manufacturers of scales. Scales weighing in ounces divided into hundredths also are satisfactory, but they are not in common use. Small "computing" scales for determining the moisture percentage

directly on the beam or on revolving charts attached to the scale are on the market. Some of them, however, are of rather small capacity. Figures 9 and 10 illustrate two types of scales used for making moisture determinations.

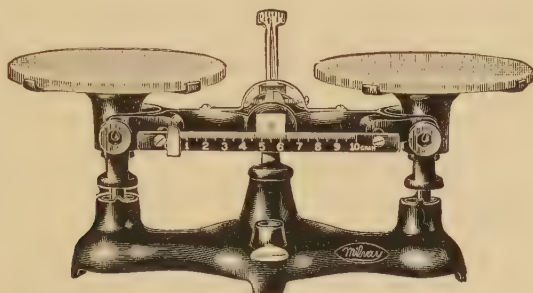


FIG. 9.—Balance for weighing moisture-test sections.

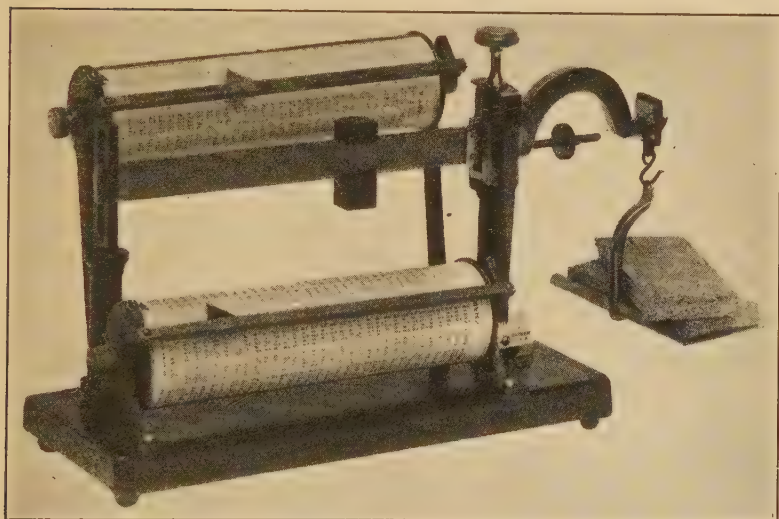


FIG. 10.—Troemroid scalometer. (Courtesy, National Dry Kiln Co.)

21. Variation in Moisture Content. (a) *In Green Wood.*—The moisture content of green wood ranges from about 20 per cent in the heartwood of eastern red cedar to about 250 per cent in some western conifers.

As a rule, the sapwood contains a considerably larger percentage of moisture than the heartwood, especially in the conifers,

but this is not always the case. In cypress, tamarack, sugar pine, and many hardwoods there is little difference in the moisture content of heartwood and sapwood. In fact, both may be so saturated with water that the logs will not float.

As a rule, the butt logs contain more moisture than the top logs. Sugar pine, redwood, and western red cedar butt logs often sink in the mill pond while top logs float. Analysis of redwood at the Forest Products Laboratory showed a moisture content of 136 to 154 per cent for the butt logs and 66 to 81 per cent for the top logs. "Sinkerstock," however, contains much more water.

Contrary to the general belief among lumbermen, there is practically no difference in the moisture content of trees at different seasons of the year. The popular belief is that the sap goes down to the roots or into the ground in the fall and comes up in the spring; hence, the expressions "sap is down" and "sap is up" are common. If such were the case, timber cut in the winter would be much lighter than that cut in the summer. Experience and scientific research, however, do not show that any such difference in weight exists. In fact, it has been found that a greater proportion of maple logs float in the summer than in the winter.

A great many moisture determinations have been made on freshly cut timber at different seasons of the year. Table III gives data derived from widely different sources. From this table it may be seen that there is no great variation in the moisture content of green timber with the seasons, but what slight differences do exist usually are in favor of a larger percentage in winter-cut timber.

What, then, is the origin of the belief that the sap is down in the winter and up in the spring and summer? Probably the fact that some trees bleed so easily in spring, and that maple sap flows in abundance after a few warm days in late winter, but not at other seasons. This ready flow of sap in the spring does not necessarily mean that there is a decided increase in the amount of sap in the tree; it only indicates that there is more pressure back of it. In fact, the pressure in tree trunks has been measured with gages and has been found to range up to 24 pounds per square inch in sugar maple and up to 33 pounds per square inch in birch in early spring, while later in summer there was found to be a partial vacuum in the stems.¹

¹ JONES, C. H., EDSON, A. W., and MORSE, W. J., "The Maple Sap Flow," Vermont Agricultural Experiment Station *Bull.* 103.

TABLE III.—PERCENTAGE OF MOISTURE IN GREEN WOOD AT DIFFERENT TIMES OF THE YEAR

Month	Arbor-vitæ ^a	Douglas fir ^b	Average of 24 European hardwoods ^c	Average of five European conifers ^c	European birch ^d	Chest-nut ^e	Loblolly pine ^f	
							Sapwood	Heart-wood
Jan.....	..	40	47	60	46	91	Winter 109	58
Feb.....	..	47	48	58	46			
Mar.....	..	49	44	59	45	89	Spring 107	48
Apr.....	82	38	43	54	..			
May.....	74	40	43	60	..			
June.....	84	33	41	61	38	89	Summer 107	57
July.....	84	28	45	60	41			
Aug.....	77	39	..	..	39			
Sept.....	71	..	43	58	38	88	Autumn 100	47
Oct.....	87	34	..	..	..			
Nov.....	80	42	40	58	41			
Dec.....	90	39	..	..	43			

^a Average of 50 poles cut each month (except January, February, and March) near Metropolitan, Mich. Forest Service Circular 136, "The Seasoning and Preservative Treatment of Arbor-vitæ Poles."

^b Average of 200 ties cut each month (except September) near Tacoma, Wash. Forest Service Circular 146, "Experiments with Railway Cross-ties."

^c NÖRDLINGER, DR. H., "Die Technischen Eigenschaften der Hölzer," 1860.

^d BÜSGEN, M., "Das Bau und Leben Unserer Waldbäume," Jena, 1897.

^e Average of 1,600 poles cut in the eastern United States. Compiled from Forest Service Circular 103, "Seasoning of Telephone and Telegraph Poles."

^f Average of several thousand cross-arms cut in North Carolina. Compiled from Forest Service Circular 151, "The Preservative Treatment of Loblolly Pine Cross-arms."

This increase in pressure of the sap in early spring is due to the absorption of soil moisture by the roots and the renewal of life activities within the tree trunk before the leaves are out. When the leaves come out, this pressure is relieved because some of the sap moves into the leaves, where it is evaporated. Therefore, while the sap content of trees may be slightly greater just before the buds burst,¹ in many trees it is less after the leaves are out than it was in winter.

(b) *In Air-dried Wood.*—If pieces of wood of small dimension are exposed to the outdoor air for a long time, they will finally attain a constant and minimum moisture content, which is from

¹ Experience shows that a larger percentage of green logs sink in late winter or early spring than in other seasons, evidently because of a higher moisture content at that time.

12 to 15 per cent in the greater part of the United States, although after a hot, dry spell of weather small pieces of wood have been known to have a moisture content of only 10 per cent in the Mississippi Valley and less in the western arid regions. Table IV gives the moisture content of certain species exposed to the outdoor air for two years in a shed at New Haven, Conn. The pieces measured $1\frac{1}{2}$ by $1\frac{1}{2}$ by 8 inches.

TABLE IV.—MOISTURE CONTENT OF SMALL BLOCKS THOROUGHLY AIR DRIED AT NEW HAVEN, CONN.

SPECIES	MOISTURE, PER CENT
Longleaf pine.....	13.3
Loblolly pine.....	14.7
Red spruce.....	15.0
White pine.....	13.4
Douglas fir.....	14.1
White ash.....	14.4
Hard maple.....	14.9
Black ash.....	14.9
Red gum.....	14.9
Chestnut.....	13.8
Average.....	14.3

In the arid Southwest, thoroughly air-dried specimens reach a still lower moisture content, while in the Pacific Northwest and along the Gulf Coast it will not become so low.

Large timbers season very slowly. Some yellow pine bridge timbers 12 by 12 inches and others 8 by 16 inches, tested by the Forest Service, contained an average of 18 per cent moisture in the portion extending from the surface halfway to the center, and 25.7 per cent in the remaining inner core after two years of seasoning.¹ In practice these would probably never become drier in outdoor structures. Redwood timbers, 8 by 16 inches in cross-section, contained 17 per cent moisture in the outer shell and 33 per cent in the core after twenty months of seasoning.

Lumber is often considered air dry before it has reached 15 per cent moisture. Lumbermen sometimes use the expressions 80 per cent dry or 90 per cent dry, meaning that the lumber has lost about 80 or 90 per cent of the total moisture it is possible to lose in air drying. This does not mean that only 20 to 10 per cent moisture is left in the wood. In fact, it is a very indefinite way of expressing the moisture condition.

¹ HATT, W. K., "Strength of Structural Timbers," Forest Service Circular 115, 1907.

(c) *In Kiln-dried Wood.*—When wood is properly kiln dried, it still contains some moisture, the amount of this moisture depending upon the purpose for which the lumber is to be used.

For furniture and cabinet work, to be used in heated buildings, the moisture content of the lumber at the time it is worked up should range from 4 per cent in winter when the shop is heated to 6 per cent in summer. If the humidity in the shop is kept above 30 per cent during winter, a moisture content of 6 per cent will also be satisfactory.

For interior finish and flooring it may be slightly more—5 to 7 per cent—because they are often stored for a long time in unheated open buildings where they will pick up several per cent of moisture if drier.

For outdoor uses, where tight joints are desired, as in airplanes and wagon wheels, it should be 7 or 8 per cent for the eastern United States. For the southwestern portion it should be about 2 or 3 per cent less, and for other parts of the country where the humidity is generally high it should be 2 or 3 per cent more. If, in the process of manufacture, wooden parts pass through warm, unhumidified rooms, it may be necessary to regulate the moisture content of the wood to suit manufacturing conditions rather than the ultimate use.

Even packing boxes have an optimum moisture content at which they give best service under ordinary conditions. This has been found to be from 12 to 15 per cent.

For less exacting demands, as sheathing, roof boards, etc., lumber is often kiln dried just to remove the bulk of the moisture. Such wood may contain anywhere from 10 to 25 per cent moisture.

(d) *In Oven-dried Wood.*—Heating wood to 212°F. does not remove every trace of water; but if the wood is heated at higher temperatures, it begins to decompose. Therefore, wood dried at 212°F. until it does not become any lighter is considered as having 0 per cent moisture for all practical purposes. For exacting chemical work, wood is heated at 221 to 225°F. to remove the hygroscopic moisture. Even at 212°F. wood will gradually decompose, and, therefore, it is advisable not to heat moisture-test sections longer than 48 hours before their final weights are taken.

22. The Fiber-saturation Point.—As was stated in the previous chapter, green or wet wood contains water in both the cell

cavities and the cell walls, the latter being saturated with the moisture. When wood dries, the cell cavities become empty first; and when these lose all their water, the cell walls begin to dry out. Wood does not begin to shrink, nor does it become stronger, until the cell walls begin to dry.

The condition, therefore, in which the cell cavities are empty but the cell walls are still fully saturated is an important point in drying. It has been called by Tiemann the "*fiber-saturation point*."¹ It ranges from 20 to 35 per cent moisture, and occurs in most woods between 25 and 30 per cent.

In practice, as wood dries, the cells near the surface dry to below the fiber-saturation point before the cells on the interior have reached that condition. This means that the outer portion or "shell" tends to shrink while the interior does not, a condition which may produce a great deal of trouble, as will be explained later.

23. Effect of Moisture and Drying on the Properties of Wood. The amount of moisture in wood is an important factor in its seasoning and in its subsequent utilization. The following properties which are of importance in the use of wood are affected by the moisture content, or degree of seasoning:

(a) *Weight*.—The water in wood may add greatly to the weight of the wood; in fact, in some woods it weighs more than the wood itself, materially increasing the cost of handling and shipping. As stated in the first chapter, one reason for kiln drying lumber is to reduce the weight so that it may be shipped at lower expense.

(b) *Strength*.—Dry wood, as a rule, is considerably stronger than green wood in all respects except in shock-resisting ability and resistance to shear, which may even be slightly decreased as wood is seasoned. This will be discussed in detail in Chap. XI.

(c) *Shrinking and Swelling*.—Whether wood will shrink, swell, or warp, after it is put into use, depends upon whether it has the proper moisture content for the condition under which it is to be used. To know when to stop the drying of lumber is important as well as to know how to dry it without deterioration.

(d) *Durability*.—It is well known that wood which is kept moist is subject to decay, while thoroughly air-dried or kiln-dried stock, if kept dry, will not decay. Timber which is completely submerged so as to exclude all air will not rot because air

¹ "The Effect of Moisture on the Strength and Stiffness of Wood," Forest Service Bull. 70, p. 82.

as well as moisture is necessary in order for decay to take place. Logs which have been taken up from the bottoms of rivers and lakes, after being submerged for twenty-five years or longer, were found to be still perfectly sound.

(e) *Painting and Gluing*.—To get the best results in applying paint, the wood should be thoroughly air seasoned or kiln dried since an oil paint will not penetrate green wood satisfactorily. For lumber and veneer that are to be glued, it is necessary to dry the stock to the *proper* moisture content so that as little shrinking and swelling as possible will take place in the glued parts, otherwise the stresses produced might open up the joints.

(f) *Smoothness of Finish*.—Dry wood can be dressed smoother than green wood as a rule, although in planing some softwoods it has been found that a moisture content of about 10 per cent gives the best results. On the other hand, green wood is easier to work.

(g) *Conductivity of Heat and Electricity*.—Dry wood does not allow heat and electricity to pass through it so easily as green wood does. Hence, it takes longer for heat to penetrate to the center of air-dried lumber in a kiln than to the center of green lumber of the same kind and thickness.

(h) *Inflammability*.—As is well known, dry wood will burn more readily than green wood. In burning wet wood a large part of the heat is consumed in converting the water into steam; the steam replaces to some extent the air in immediate contact with the wood so that less oxygen is available for combustion.

(i) *Permeability by Liquids and Gases*.—In wood preservation, it is desirable to have the wood seasoned so that the preservatives will penetrate properly. If wood becomes very dry, however, moisture will not pass through it so easily as when the surface is slightly damp. Gases will not pass through wet wood so readily as through dry wood.

24. Does the Time of Year When Lumber Is Cut Affect Its Properties?—A common but erroneous belief of lumbermen is that timber cut in the spring or summer is inferior to fall- and winter-felled timber because the "sap is up" during the growing season. The sap, meaning not only the moisture, but the materials in solution, is believed to have certain qualities which affect the seasoning, durability, and strength of timber.

In order to discuss this subject it is necessary to consider the sapwood and heartwood separately. Experience has shown

that the sapwood always dries more readily than the heartwood, of the same species, and never is durable in damp places (unless treated), no matter at what time of the year it is cut. Even if the sap did go down in the fall and come up in the spring, this could not affect the strength of the wood since the strength depends upon the density of the wood. The heartwood of a tree is dead, and there is no "flow" of sap in it, as in the sapwood. Hence, the time of year at which it is cut could have very little influence on its properties.

The belief is also common that during the growing season the wood is not "ripe," but that in the fall and winter it is mature and is, therefore, stronger and will keep better. This could apply only to the outermost annual ring since the rest of the wood was formed in previous years and has completed its growth. The outermost annual ring is usually cut off at the mill and rarely appears in the finished product.

Since a great deal of timber is cut during the summer months, the claim is made that if the "sap," including sugars and other soluble materials, could be removed from such lumber it would be greatly improved and be more like winter-cut lumber. Extravagant claims are made for some dry kilns and special equipment that they remove not only the moisture but these other "injurious" materials as well.

If these "injurious" materials could be removed from the sapwood, it does not seem reasonable that its strength would be increased. Neither could the drying be improved upon since sapwood dries relatively quickly and easily. Decay affects the wood itself, and removing these materials would probably not increase the durability of sapwood appreciably in a damp location.

In the heartwood the strength would also not be improved by removing its soluble materials. Its durability might be *decreased*, for it is a well-established fact that the presence of tannins and other materials in the heartwood adds to its resistance to decay. The rate of drying might possibly be increased by removing these moisture-holding materials, but there is no practical method by which this can be done. Leaching the wood for a long time, especially in hot water, might accomplish this in part, but it would take months or years. Steaming does not do it. Although the condensation from steaming is often dark colored, this coloring matter very likely comes from the surface of the lumber only and not from the interior.

Why, then, is winter-cut timber so often preferred? Because the sun is lower in winter and not because the sap is down. Timber cut in summer is at once exposed to the heat of the sun and to hot-air currents and dries quickly *at the surface* but slowly in the interior. This uneven drying causes severe surface checking. Furthermore, decay, sap-staining organisms, and insects are active at that time of the year and at once attack the green wood.

Timber cut in winter dries out slowly and, therefore, does not surface check so much as timber cut during the warm season when excessive surface drying takes place. Furthermore, in winter-cut timber the surface becomes dry by the time wood-decaying and stain-producing fungi and insects become active, and, therefore, deterioration is not so great. *If the logs could be taken to the saw carriage or be put in a log pond as soon as cut, and the lumber put into a dry kiln as soon as sawed, it would make absolutely no difference whether the timber was cut in summer or in winter.*

25. Absorption of Moisture by Wood.—Wood is a hygroscopic material, which means that it has the property of taking on or giving off moisture until its moisture content corresponds to that of its surroundings.

(a) *In Water.*—If dry wood is submerged in water, it will absorb moisture rapidly at first and more slowly later so that it takes a long time for it to become fully saturated. Experiments made in leaching Douglas fir at the Forest Products Laboratory showed that sticks 4 by 8 inches and 6 feet long were not fully saturated after seven years of submersion.

If the wood is allowed to float, it may never become saturated, because the upper part dries out as rapidly as the lower part absorbs moisture. Some kinds of green timber, however, sink immediately when placed in water, while others sink in a comparatively short time.

Wood absorbs moisture much more rapidly from the ends than from the sides, and the absorption takes place more rapidly on the tangential faces than on the radial faces. The greater absorption on the tangential surfaces is due to the medullary rays which extend at right angles to them and assist in conducting the moisture into the wood.

Dry sapwood absorbs more water in a limited period of time than heartwood of the same degree of dryness. Dense woods

do not absorb so great a percentage of moisture, based on the dry weight of the wood, as light woods of the same dryness in the same length of time.

The rate of absorption also increases with the temperature. The average daily absorption of white pine heartwood over a period of nine days was found to be 0.98 per cent at 68°F. and 7.17 per cent at 180°F.¹ This shows that hot water passes through wood more rapidly than cold water, a principle which is also made use of in drying lumber.

(b) *From the Air*.—As has already been stated, wood does not dry out completely under ordinary atmospheric conditions. It retains more or less moisture, depending upon the temperature and the humidity of the surrounding air. In the eastern part of the United States this is 12 to 15 per cent, as shown in Table IV. If wood is stored in a heated room for some time, the moisture content drops to between 4 and 10 per cent, as a rule. If it is again exposed to more humid conditions, it absorbs moisture. This is responsible for the shrinking and swelling of wood, or "working" as it is called.

Table V shows the variation in moisture content of uncoated 2-inch lumber in a furniture factory in Grand Rapids, Mich. The relative humidity of the atmosphere in the factory during the same period of time fluctuated from 15 per cent in winter to 67 per cent in summer.²

TABLE V.—MOISTURE CONTENT OF RED GUM AND CHESTNUT SAMPLES 2 INCHES THICK IN FURNITURE FACTORY IN MICHIGAN

DATE	MOISTURE CONTENT, PER CENT
Mar. 15, 1919.....	3.78
Apr. 15, 1919.....	4.35
May 15, 1919.....	6.50
June 15, 1919.....	7.40
July 15, 1919.....	7.60
Aug. 15, 1919.....	7.80
Sept. 15, 1919.....	7.00
Oct. 15, 1919.....	6.20
Nov. 15, 1919.....	5.20
Dec. 15, 1919.....	4.30
Jan. 15, 1920.....	4.00

¹ EDWARDS, ANN E., "Comparison of the Rate and Direction of Absorption in Various Commercial Woods When Immersed in Water," Forest Products Laboratory Report, 1915-1916.

² *Hardwood Record*, Nov. 25, 1913.

There is a definite relation between the moisture content of wood and the relative humidity of the atmosphere at any given temperature. This is shown by the curves in Fig. 11. The upper curve in the figure shows the moisture content which wood will attain when subjected to different humidities at ordinary room temperature (70°F.). At a humidity of 68 per cent, for instance, wood, if wet, will dry out to approximately 13 per cent; or if it is very dry, it will absorb moisture to about 13 per cent of its weight.¹ In fact, the dry wood will not attain

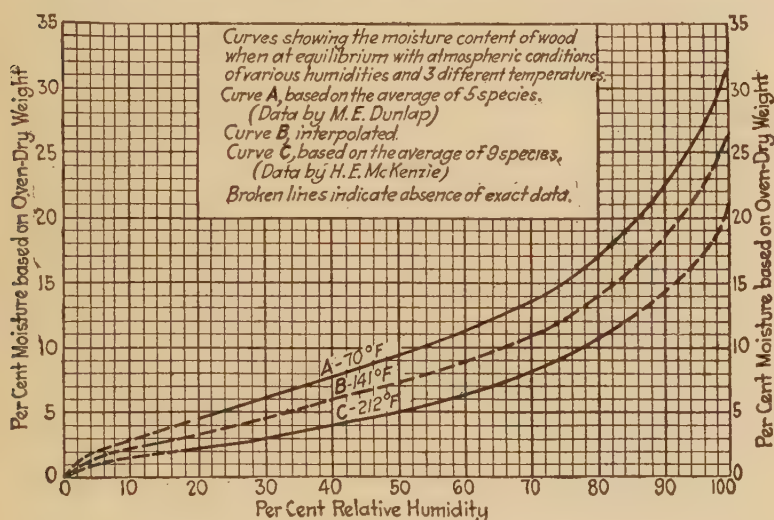


FIG. 11.—Relation of moisture content of wood to relative humidity

quite so high a moisture content as 13 per cent, and the green wood will not become quite so dry. The curve represents the average moisture content of wet wood losing moisture and dry wood gaining moisture at certain humidities.

At higher temperatures, as in a dry kiln, the wood will not hold quite so much moisture for any given humidity. The lowest of the three curves in Fig. 11 indicates the average moisture content of wood at 212°F. and various humidities.

The curve at 141°F. is interpolated halfway between the other two curves. Recent observations show that this curve should be

¹ To "work the curve" follow the vertical line, representing the specified relative humidity, upward until it intersects the curve, then see what horizontal line strikes the curve at about the same point. The percentage of moisture represented by the horizontal line corresponds to that of wood subjected to the given humidity.

somewhat lower, although its exact location has not been determined. With this fact in mind, curves for other temperatures may be interpolated fairly accurately.

Wood exposed to 100 per cent humidity will take on moisture practically indefinitely, or until it approaches saturation, although the absorption is very slow after the wood has taken on a considerable amount.

Although these curves are based on only a very limited number of species of wood, the tests showed that the different species were remarkably similar in their moisture-humidity relations. It is believed that these curves are reasonably accurate for almost all woods. The definite relation of moisture content to humidity has an important bearing on the humidities used in dry kilns, dry storage sheds, wood-working shops, and warehouses.

Tests on wood show that if it is subjected to high temperatures, say over 150°F., for any length of time, the hygroscopicity is reduced. The higher the temperature and the longer the time of treatment the more pronounced is the effect. Tests made on the effect of kiln drying on the hygroscopicity of wood showed that boards kiln dried at temperatures ranging from 145 to 274°F. and then placed under cover in an open shed for one year absorbed moisture up to 9.1 per cent on the average; whereas matched pieces, which had been in the shed for two years and not kiln dried, came down to 12.3 per cent on the average.

CHAPTER IV

SHRINKAGE AND COLLAPSE

26. Shrinking and Swelling.—Among the main sources of trouble in the seasoning, manufacture, and use of lumber are shrinking and swelling, which occur with changes in moisture content. If the contraction and expansion were uniform throughout a piece of lumber, comparatively little trouble would result therefrom, but because the shrinking and the swelling nearly always are uneven, it checks and becomes distorted in shape, or stresses are set up in it.

Although shrinking cannot be prevented in drying, or swelling in reabsorption of moisture, a good understanding of these phenomena will go a long way in reducing to a minimum the difficulties resulting therefrom. The fact that wood is used in preference to other materials for airplane propellers, a product in which correct shape and balance are absolutely essential, shows that when properly handled it can be used for very exacting purposes.

Various treatments have been advocated for preventing shrinkage; for example, soaking in oils, impregnations with sugars, and exposure to high temperatures, but none of these prevents shrinkage, although it may reduce it.

The force exerted by wood in shrinking and swelling is tremendous. It is sufficient to pull the fibers apart as the wood shrinks or to crush them as it swells, the latter requiring a pressure of from over 300 pounds per square inch in wet western red cedar to over 1,500 pounds per square inch in live oak. If dry wood absorbs moisture while it is confined so that it cannot swell, it becomes compressed; part of the compression may be permanent so that when the wood dries and shrinks again it will be smaller than it was in its previous dry condition. Sometimes the swelling of wood is advantageous, as in operating humidity regulators, tightening handles in tools, tires on wheels, and joints in barrels, tanks, and boats.

27. Relation of Shrinkage to Moisture Content.—In the preceding chapter it was stated that wood does not begin to shrink in drying until the moisture content is below the fiber-saturation point. On the other hand, if dry wood absorbs moisture it does

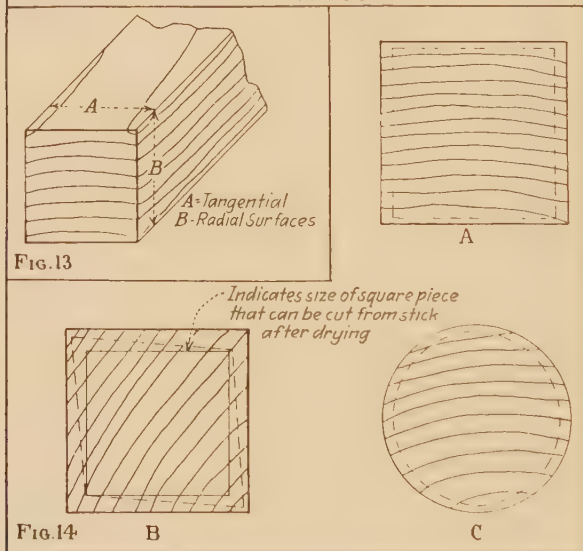
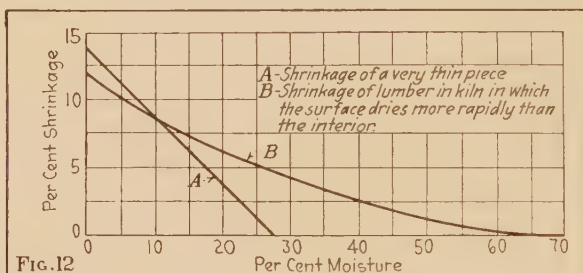


FIG. 12.—Approximate curves for tangential shrinkage of a heavy wood.

FIG. 13.—A, tangential, B, radial surfaces.

FIG. 14.—End views of square and round pieces distorted in shape in drying, on account of tangential shrinkage being greater than radial. Broken lines indicate shape of dry pieces.

not swell any more after the fiber-saturation point is reached. In the drying of oak, eucalyptus, and a few other woods, however, considerable apparent shrinkage takes place before the fiber-saturation point is reached. This is due, very likely, to collapse of the cells, which will be explained later.

If the shrinkage of a thin piece of wood is plotted against its moisture content, the curve will appear something like *A* in Fig. 12. Below the fiber-saturation point the shrinkage is proportional to the amount of moisture lost. Assume a piece of wood as having the fiber-saturation point at 25 per cent moisture content; then if it is dried to 12 per cent (thoroughly air-dry condition), about half of its possible shrinkage will have taken place; and if it is dried to 6 per cent, about three-fourths of its possible shrinkage will have occurred, provided the wood is dried fairly uniformly.

It is usually found in measuring the shrinkage of green boards or other stock from time to time while drying, that there is a slight shrinkage from the very beginning of the drying period. This is due to the outer fibers drying to below the fiber-saturation point long before the wood in general has become that dry. A curve of the shrinkage of lumber dried in the kiln looks like *B* in Fig. 12.

28. How Shrinkage Is Measured and Expressed.—Shrinkage in the width of lumber can be determined accurately by drawing a line across the face of a board having square edges and making frequent measurements along this line during the drying period. Several boards should be measured in this way in order to obtain a good average. A finely graduated hook scale is best for this purpose. When samples are to be tested, care should be taken to see whether most of the lumber is plain sawed or quarter sawed, and the samples chosen accordingly. Shrinkage in thickness can best be measured with a caliper. Shrinkage in volume can be determined by immersing the wood in water before and after drying and quickly observing the displacements. For determining the displacement of dry pieces it is necessary to dip them in hot paraffin beforehand so that they will not absorb moisture.

The shrinkage of wood with change in moisture content may be expressed in percentage, based either on the original size or on the dry size. In determining the percentage change in dimensions from the green to the dry condition the former is preferred as a basis because green wood is in a natural condition and has a constant volume, while the dry volume varies with the method of drying, as will be explained later. The shrinkage percentages given in Table VII are based on the green sizes.

29. Extent of Shrinkage Along and Across the Grain.—It is well known that wood shrinks differently in different directions

with respect to its grain. The shrinkage is least in the direction parallel to the fibers and greatest in the direction at right angles to the fibers and tangent to the annual rings. The values given in Table VI represent the range in the shrinkage of wood in drying it from the green to the oven-dry condition. In practice, wood is not used in the oven-dry condition; and hence the shrinkage is only in proportion to the amount of moisture lost below approximately 25 per cent.

TABLE VI.—RANGE IN SHRINKAGE OF NATIVE WOODS FROM GREEN, OR OVER 30 PER CENT MOISTURE, TO OVEN-DRY

	PER CENT
Longitudinal, normally.....	0.10 to 0.35
Across the grain:	
Radially.....	2.0 to 8.5
Tangentially.....	4.0 to 14.0
In volume.....	7.0 to 21.0

The shrinkage of lumber along the grain is, as a rule, so little as to be negligible for most purposes. Some woods, however, are said to shrink to an unusual extent longitudinally, making the shrinkage quite noticeable in long pieces, as in siding; but if they are properly dried before they are put into place, the longitudinal shrinkage is not a serious factor. The outer wood of some trees shrinks more longitudinally than that nearer the center, causing boards cut from it to bow lengthwise. This tendency has been noticed particularly in birch and elm.

Certain kinds of abnormal wood shrink excessively longitudinally. The so-called "compression wood," formed on the lower side of leaning conifers and on the underside of coniferous branches, shrinks considerably lengthwise. Pieces cut out of a yellow pine beam containing compression wood have been found to shrink as much as 3.25 per cent longitudinally in drying from the wet to the oven-dry condition.

Light pieces of tupelo and cypress have been found to shrink longitudinally as much as 1.25 and 1.4 per cent, respectively. Light wood, in general, probably will shrink more longitudinally than heavier wood of the *same kind*.

On the average, the shrinkage across the grain is about twice as much in the direction of the annual growth rings (tangentially) (Fig. 13A) as at right angles to them (radially) (Fig. 13B), a fact which makes quarter-sawed lumber more desirable for many purposes. This difference in shrinkage causes the shape

of the wood to be distorted in drying. Square pieces, in which the rings, as seen on the ends, run parallel to two faces, become oblong (Fig. 14A). If the rings run diagonally from corner to corner, the piece becomes diamond-shaped (Fig. 14B); and round pieces become oval (Fig. 14C). The "diamonding" of heavy oak stock causes considerable loss, as the square size that can finally be obtained from such stock is small compared with the original piece, as is indicated in *B* in Fig. 14. As far as possible, heavy stock should be cut so that the rings do not run diagonally across the ends.

Table VII gives the volumetric, radial, and tangential shrinkage and the ratio of the tangential to radial shrinkage for numerous woods. It will be seen that in some woods, as birch and mahogany, the tangential shrinkage is only slightly greater than the radial, while in willow it is three times as great.

The radial shrinkage is less than the tangential shrinkage because the medullary ray cells, as was previously stated, run radially in a tree at right angles to the grain. These cells, like the vertical fibers, shrink very little in length, and since their longest axis is at right angles to the fibers, they prevent the fibers from shrinking to the full extent transversely in a radial direction. There is nothing to interfere with the full shrinkage of the fibers tangentially; that is, with the rings of growth.

It will be noticed from Tables VI and VII that there is wide variation in the total shrinkage of woods even in the same direction. As a general rule, the heavy woods shrink and swell more transversely than the light woods with corresponding changes in moisture per cent. Black locust and osage orange (*Bois d'Arc*) are some exceptions. They do not shrink so much as would be expected from their weight. This quality, together with their great durability and strength, makes these woods excellent for felloes of wagon wheels to be used in very hot and dry climates, as in the Southwest. Basswood, on the other hand, is a light wood, but it shrinks and swells more than would be expected from its weight.

The relation between the shrinkage and weight, or specific gravity, of different species of wood is shown graphically in Fig. 15. Even in the same species the lighter pieces shrink less than the heavier pieces of that species. For example, some of the lightest ash wood tested at the Forest Products Laboratory shrunk 8.4 per cent in volume while the heaviest ash shrunk

16 per cent. Because light woods, in general, shrink less, they give less trouble in kiln drying than heavy woods. Whenever a

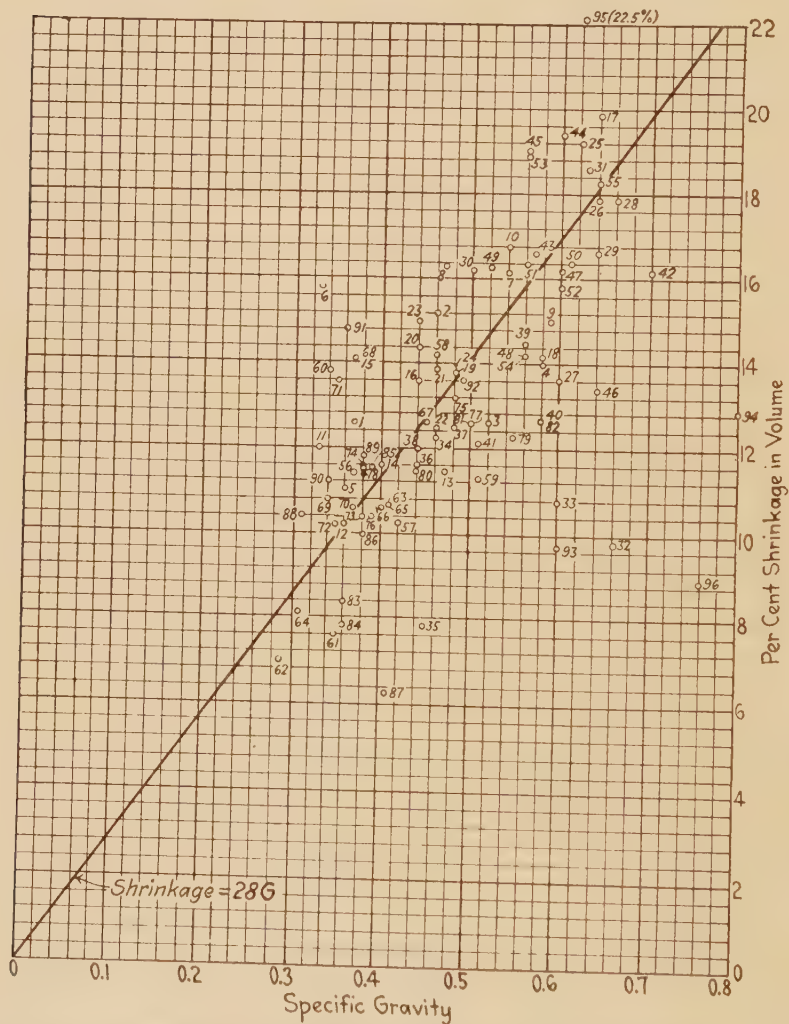


FIG. 15.—Relation between shrinkage in volume and specific gravity of various species of wood. Reference numbers refer to species in Table VII, except 94, 95, and 96 which are greenheart, eucalyptus (blue gum), and osage orange, respectively.

minimum amount of shrinking or swelling is desired in wooden articles, a wood as light as will stand up under the conditions should be selected.

As a rule, heartwood and sapwood, when of the same density, shrink and swell equally with equal changes in moisture content. If the sapwood is less dense than the inner heartwood, as often happens in mature trees, it may shrink and swell less. On the other hand, sapwood responds more quickly to changes in atmospheric humidities, and, therefore, may appear to change more in size during short periods of time. Heartwood sometimes decreases in size considerably more in drying than sapwood, but this is due to collapse of the cells, which will be explained later.

It has been found that when green woods are dried at a high temperature and low humidity they do not shrink so much as if dried at a higher humidity, presumably because in the former case the drying is more uneven and portions of the wood become dry and set without full shrinkage before adjacent parts are as dry. These set portions finally keep the entire piece from shrinking normally. Slow and careful drying, therefore, usually produces more shrinkage in lumber than forced drying, but this difference is negligible when the difference in the quality of the stock is considered.

Shrinking and swelling of wood can be reduced by subjecting it to high temperatures. The higher the temperature and the longer it is maintained the more effective the treatment. The swelling of ash steamed at 28 pounds pressure (271.3°F.) for twenty hours was reduced to one-half that of unsteamed ash in experiments at the Forest Products Laboratory. Temperatures such as are usually maintained in a dry kiln probably also reduce subsequent shrinking and swelling, since, as already stated on page 44, heat reduces the hygroscopicity of wood, although definite data on the effect on shrinking and swelling are lacking.

It is claimed that lumber cut from logs which have been in water for a year or longer will not change in size and shape so much as lumber cut from fresh logs.

30. How to Secure a Minimum of Shrinking and Swelling of Wood during Manufacture and When in Use.—Several precautions can be taken in selecting and preparing wood for purposes where a minimum of shrinking and of swelling in width is essential:

1. Use as light a wood as will stand up under the conditions.
2. Use quarter-sawed material.

TABLE VII.—SHRINKAGE IN PER CENT OF GREEN DIMENSION OF COMMON

Species	In volume	Radially	Tangen- tially	Ratio of tangential to radial shrinkage Radial = 1
<i>Hardwoods</i>				
1. Alder, red.....	12.6	4.4	7.3	1.61
2. Ash, black.....	15.2	5.0	7.8	1.56
3. " , white (forest grown).....	12.6	4.2	6.5	1.55
4. " , white (second growth).....	14.0	5.3	8.7	1.64
5. Aspen, trembling.....	11.1	3.3	6.9	2.09
6. Basswood.....	15.8	6.6	9.3	1.41
7. Beech.....	16.2	4.8	10.6	2.21
8. Birch, paper.....	16.3	6.6	8.8	1.33
9. " , sweet.....	15.0	6.3	7.6	1.21
10. " , yellow.....	16.8	7.4	9.0	1.22
11. Buckeye.....	12.0	3.5	7.8	2.23
12. Butternut.....	10.2	3.3	6.1	1.85
13. Cherry, black.....	11.5	3.7	7.1	1.92
14. Chestnut.....	11.6	3.4	6.7	1.97
15. Cottonwood.....	14.1	3.9	9.2	2.36
16. Cucumber.....	13.6	5.2	8.8	1.69
17. Dogwood, flowering.....	19.9	7.1	11.3	1.59
18. Elm, rock.....	14.1	4.8	8.1	1.69
19. " , slippery.....	13.8	4.9	8.9	1.82
20. " , white.....	14.4	4.2	9.5	2.26
21. Gum, black.....	13.9	4.4	7.7	1.75
22. " , tupelo.....	12.5	4.2	7.6	1.81
23. " , red.....	15.0	5.2	9.9	1.90
24. Hackberry.....	13.8	4.8	8.9	1.86
25. Hickory, big shellbark.....	19.2	7.6	12.6	1.66
26. " , mockernut.....	17.9	7.8	11.0	1.41
27. " , pecan.....	13.6	4.9	8.9	1.82
28. " , pignut.....	17.9	7.2	11.5	1.60
29. " , shagbark.....	16.7	7.0	10.5	1.50
30. Holly.....	16.2	4.5	9.5	2.11
31. Hornbeam.....?	18.6	8.2	9.6	1.17
32. Locust, black.....	9.8	4.4	6.9	1.57
33. " , honey.....	10.8	4.2	6.6	1.57
34. Magnolia, evergreen.....	12.3	5.4	6.6	1.22
35. Mahogany, Central American.....	7.8	3.4	4.9	1.44
36. Maple, Oregon.....	11.6	3.7	7.1	1.92
37. " , red.....	12.5	3.8	8.1	2.13
38. " , silver.....	12.0	3.0	7.2	2.40
39. " , sugar.....	14.5	4.8	9.2	1.92
40. Oak, bur.....	12.7	4.4	8.8	2.00
41. " , California black.....	12.1	3.6	6.6	1.83
42. " , canyon live.....	16.2	8.0	14.3	1.79
43. " , chestnut.....	16.7	5.5	9.7	1.76
44. " , cow.....	19.4	5.9	9.2	1.56
45. " , laurel.....	19.0	3.9	9.5	2.44
46. " , Pacific post.....	13.4	4.	9.0	2.14
47. " , post.....	16.2	5.4	9.8	1.81
48. " , red.....	14.2	3.9	8.3	2.13

AMERICAN WOODS IN DRYING FROM THE GREEN TO THE OVEN-DRY CONDITION

Species	In volume	Radially	Tangen- tially	Ratio of tangential to radial shrinkage Radial = 1
49. Oak, Spanish highland.....	16.3	4.5	8.7	1.93
50. " , Spanish lowland.....	16.4	5.2	10.8	2.08
51. " , water.....	16.4	4.2	9.3	2.21
52. " , white.....	15.8	5.3	9.0	1.70
53. " , willow.....	18.9	5.0	9.6	1.92
54. " , yellow.....	14.2	4.5	9.7	2.16
55. Persimmon.....	18.3	7.5	10.8	1.44
56. Poplar, yellow.....	11.4	4.1	6.9	1.68
57. Sassafras.....	10.3	4.0	6.2	1.55
58. Sycamore.....	14.2	5.1	7.6	1.49
59. Walnut, black.....	11.3	5.2	7.1	1.37
60. Willow, black.....	13.8	2.6	7.8	3.00
<i>Conifers</i>				
61. Cedar, incense.....	7.8	3.3	5.7	1.73
62. " , northern white.....	7.0	2.1	4.9	2.33
63. " , Port Orford.....	10.7	5.2	8.1	1.56
64. " , western red.....	8.1	2.5	5.1	2.04
65. Cypress, bald.....	10.7	3.8	6.0	1.58
66. Fir, Douglas (Rocky Mountain).....	10.6	3.6	6.2	1.72
67. " , Douglas (Pacific Coast).....	12.6	5.0	7.9	1.58
68. Fir, amabilis.....	14.1	4.5	10.0	2.22
69. " , balsam.....	10.8	2.8	6.6	2.36
70. " , grand.....	10.6	3.2	7.2	2.25
71. " , noble.....	13.6	4.9	9.1	1.86
72. " , white.....	10.2	3.4	7.0	2.06
73. Hemlock, eastern.....	10.4	3.0	6.4	2.13
74. " , western.....	11.6	4.5	7.9	1.76
75. Larch, western.....	13.2	4.2	8.1	1.93
76. Pine, jack.....	10.4	3.4	6.5	1.91
77. " , loblolly.....	12.6	5.5	7.5	1.36
78. " , lodgepole.....	11.5	4.5	6.7	1.49
79. " , longleaf.....	12.3	5.3	7.5	1.42
80. " , Norway.....	11.5	4.6	7.2	1.57
81. " , shortleaf.....	12.6	5.1	8.2	1.61
82. " , slash.....	12.7	5.9	7.5	1.27
83. " , sugar.....	8.4	2.9	5.6	1.93
84. " , white, eastern.....	7.8	2.2	5.9	2.68
85. " , white, western.....	11.5	4.1	7.4	1.80
86. " , yellow, western.....	10.0	3.9	6.4	1.64
87. Redwood.....	6.3	2.7	4.2	1.55
88. Spruce, Englemann.....	10.4	3.4	6.6	1.94
89. " , red.....	11.8	3.8	7.8	2.05
90. " , Sitka.....	11.2	4.5	7.4	1.64
91. " , white.....	14.8	3.7	7.3	1.97
92. Tamarack.....	13.6	3.7	7.4	2.00
93. Yew, western.....	9.7	4.0	5.4	1.35

3. Have the wood dried to the proper moisture content to begin with, so that it will neither give off nor absorb a great deal of moisture when in use.

4. Use cross-banded material.

5. Use wood which has been subjected to high temperatures, as in a kiln or steaming cylinder, when this is practicable.

6. Protect the lumber or finished product from great and sudden changes in atmospheric humidity.

Besides the above precautions, use several coats of paint, oil, varnish, enamel, shellac, or other protective coating to reduce the change in volume if the wood is subjected to a change in surrounding humidity for a limited period of time.

31. Cupping and Twisting.—By cupping is meant the curving up or down of both edges of a board, producing a trough or

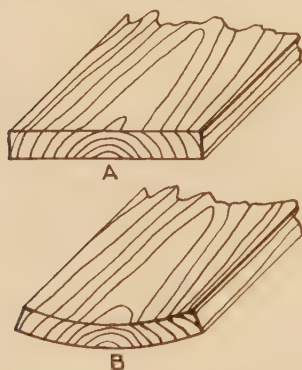


FIG. 16.—Cupping of plain-sawed lumber in drying, A, green; B, dry.



FIG. 17.—Twisting of lumber in drying.

ridge, with the edges still parallel. It is due to one or more of the following causes:

1. One side drying and shrinking more rapidly than the other, as when wet lumber is laid on the ground and the sun dries out the upper surface. Cupping due to uneven drying is temporary; and when the lumber becomes uniformly dry, it will straighten out more or less.

2. One side shrinking more than the other even if dried uniformly, as in plain-sawed lumber. In plain-sawed lumber the side toward the center of the tree is more nearly like a quarter-sawed surface than the other side, and, since wood shrinks less in width the more nearly it is cut radially, the side toward the center shrinks less. This causes the board to cup away from the

center, as in Fig. 16.* In drying plain-sawed lumber in a pile, the weight of the lumber above each piece keeps it straight. Lumber in the top courses usually cups if it has no other weight on it.

3. When lumber which is much drier on the surface than in the interior is resawed, the edges turn away from the saw. This form of cupping also is temporary, and, as the freshly exposed surfaces dry, the lumber may straighten out, or even curve the other way.

4. Casehardened lumber also cups when resawed, or when more is dressed off from one side than the other. This will be fully explained under Casehardening.

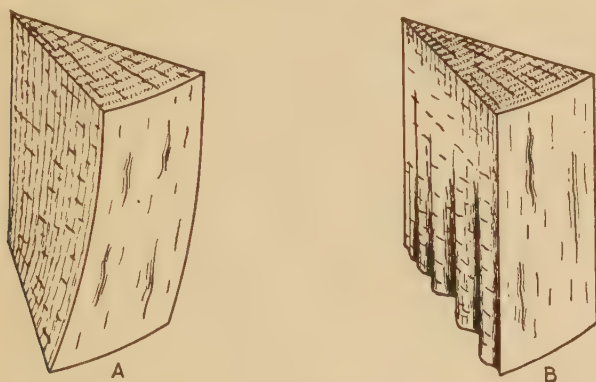


FIG. 18.—Split radial surfaces showing spiral grain, *A*; and interlocked grain, *B*.

5. Parts of furniture, fixtures, interior finish, etc. which receive more paint or varnish on one side than on the other may cup when exposed to sudden changes in atmospheric humidity, as the side with the more moisture-resistant coating will not take on or give off moisture so rapidly as the other side.

In twisted lumber the edges are no longer parallel. See Fig. 17. This may be due to uneven drying, but often it is due to spiral or interlocked grain, which causes uneven shrinkage. In Fig. 18, *A* illustrates what is meant by spiral grain, and *B* what is meant by interlocked grain. Black gum, tupelo gum, red gum, cottonwood, elm, sycamore, beech, and other woods with interlocked grain must be dried carefully or they will twist. In mahogany the grain is also interlocked, but it seems to be an exception and gives very little trouble in twisting.

Careful piling of the lumber, with stickers close together and properly aligned over each other, is the best safeguard against twisting during drying. When lumber twists after it is dried, this indicates that it is either giving off or taking on moisture. Serious twisting may be reduced by drying the lumber to the proper moisture content in the first place and taking proper care of it afterward. Quarter-sawed lumber twists less than plain-sawed. Sap gum twists more than heart or "red" gum, probably because the sap gum usually is plain sawed while the heartwood is often quarter sawed, and because the cross-grain is more pronounced in the outer part of a tree trunk than near the center.

To prevent or to reduce twisting of wood during manufacture or after it is in use, the following precautions should be observed as far as is practicable:

1. Select species which do not twist easily, avoiding especially woods with spiral or interlocked grain, or uneven density.
2. Use quarter-sawed lumber.
3. Have the wood properly dried.
4. Protect the wood against extremes of atmospheric humidities.

The word "warping" is often used to mean twisting, but it is also used for cupping or any distortion of the plane surface.

32. Checking.—The checking of lumber is due to two causes:

(a) *Uneven Drying.*—The ends of lumber in a pile dry out more rapidly than the portions further back because the end grain gives off the moisture more rapidly and also is more exposed to the drying influences of the air. This causes uneven shrinkage and, particularly in the heavier woods, severe end checking.

If lumber dries rapidly at a low humidity, the surface layers become dry and tend to shrink before the interior has become as dry. As a result, the surface often checks. These checks do not penetrate far; and later when the interior dries and shrinks, they may close up, but they do not heal up. If a thin cross-section is taken from such boards, it often can easily be broken along the checks.

End checking can be reduced to some extent in air drying by shading the ends of the pile or by nailing wooden or metal cleats across the ends of the boards, as is done with some hardwoods. In kiln drying, end checking can be reduced by keeping the humidity fairly high. Another method of reducing end

checking which applies to both air drying and kiln drying is to coat the ends of lumber or other stock with some moisture-retarding material.

The coatings ordinarily used can be divided into two classes: (1) a liquid at ordinary temperatures, which can be applied cold; (2) a solid at ordinary temperatures, which must be applied hot. Cold coatings may be used as easily on logs and lumber as on kiln samples and dimension stock; hot coatings, because of the method of application (end dipping), are not easy to use on large stock.

Either the cold or the hot coatings can be used effectively for drying temperatures up to 140°F. Temperatures much above this cause blistering in the cold coatings but make the hot coatings plastic enough to form new surfaces as fast as the old ones break. For this reason the hot coatings are apt to be more effective than the cold coatings for temperatures from 140 up to 170°F., where they liquefy to such an extent that they run off. No coating has been found which is entirely satisfactory for temperatures above 170°F. Cold coatings are perhaps somewhat better than hot coatings for temperatures above 170°F. and for use on kiln samples when the temperatures are high enough to cause the loss of part of a hot coating.

Cold coatings, to be effective, should have about the consistency of heavy syrup. The amount of filler required ranges from one-half to four parts by weight to one of the vehicle. Cold coatings used at the Forest Products Laboratory have been found effective about in the following order, the most effective being placed first:

Hardened gloss oil thickened with barytes and asbestine. . . .	Very cheap
Chinawood oil and barytes.	Cheap
Linseed oil and white lead (very heavy).	Moderate cost
Linseed oil and red lead (very heavy).	Moderate cost
High-grade spar varnish and barytes.	Expensive

The gloss oil coating is made as follows: The oil itself should be of a thick grade, made up (by the paint manufacturer) of about 8 parts quicklime, 100 parts rosin, and 57.5 parts spirit. To 100 parts of the gloss oil is added 25 parts of barytes and 25 parts of asbestine. One or two parts of lampblack may also be added if a black coating is desired. The asbestine assists materially in preventing the settling out of the pigment. Any paint manufacturer can make up this coating.

The hot dips are effective in the following order:

213° coal-tar pitch.....	Cheap
254° coal-tar pitch.....	Cheap
Rosin and lampblack (100 parts of rosin to 7 parts of lampblack).....	Moderate cost

Some asphalts are highly moisture-resistant, but they are hard to apply because of the high temperatures required to make them plastic.



FIG. 19.—Radial checks in end of log.

Paraffin has proved very satisfactory as an end coating for stock during air seasoning but cannot be used in the kiln because of its low melting point.

Excessive shrinkage of the wood and rough handling often cause the end coatings to chip or shear off, so that a fresh application of the coating must be made.

To reduce end drying sufficiently there must be a thick coating over the entire end surface. When hot dips are used, the wood should be dipped half an inch into the liquid.

Surface checking in air drying can be reduced by piling the lumber close together or otherwise cutting down the circulation of air through the pile. Care should be taken, however, to see that sufficient air circulation is maintained to prevent stain and decay. In kiln drying, surface checking can be prevented by keeping the humidity high. Steaming the lumber until the air is saturated is unnecessary, however.

(b) *Tangential Shrinkage Being Greater than Radial.*—Timbers containing the pith center will check more or less in drying



FIG. 20.—Cross-section of an oak timber showing how surface checks follow the medullary rays. (Courtesy, Forest Products Laboratory.)

because the wood shrinks more along the rings than toward the center and also because the central portion dries more slowly. The characteristic checking of logs is shown in Fig. 19. In timbers cut through the center, the halves can cup and thus reduce checking. When plain-sawed lumber is held flat, so that it cannot cup in drying, it is very apt to check along the middle.

One-piece porch columns, wagon wheel hubs, and artificial limbs are bored out at the center before drying to make possible

a greater radial contraction, and thus reduce checking and hasten the drying.

Checks, whether in lumber or in timbers, nearly always extend across the rings radially because the tangential shrinkage is greater than the radial and because where the rays and fibers cross, a weak plane is produced when shrinkage takes place. Figure 20 shows how the checks follow the rays in oak. Logs and timbers occasionally check with the rings on the end surfaces, but these checks are never so harmful as the accompanying radial checks.

33. Casehardening.—Casehardening, as used here, means a difference in set which produces stresses in lumber. These stresses may cause cupping or other distortion of the shape of lumber when it is resawed or otherwise worked up. Casehardening is perhaps a poor term for this condition, but it is used because it has become an established term in the wood-using industries.

There are other meanings of the term, which unfortunately causes considerable misunderstanding. A common conception of casehardening is that the surface of the lumber is dry and the interior is wet.¹ This, however, is a temporary condition, which disappears as soon as the moisture becomes uniformly distributed. The term is also used to mean that the surface layers are harder than the interior, as when the same term is used in connection with metals. Such a condition does not occur in wood, however, except when the surface layers are drier than the center—a temporary condition.

The difference in set, which characterizes casehardening, is a permanent condition which may exist in lumber for years after moisture distribution has become uniform, although it can be relieved at any time by proper treatment.

Casehardening may be explained as follows: If, for example, lumber with 60 per cent moisture is dried in an atmosphere of comparatively low humidity, the outer layers will dry more rapidly at first than the interior, so that after several days of drying the surface will appear dry while the interior still is wet. The exact difference in the moisture content of the shell and core can be determined by making a test as described on page 27 and illustrated in Fig. 6.

¹ In drying fruits this is the accepted meaning of casehardening.

Assume that after the lumber has dried for some time the moisture content of the shell is 22 per cent while that of the core is 47 per cent. Under these conditions the surface layers of the lumber are below the fiber-saturation point and tend to shrink while the interior is still above the fiber-saturation point and is not shrinking at all, although it is losing moisture. Later, the moisture contents of the shell and core of the lumber

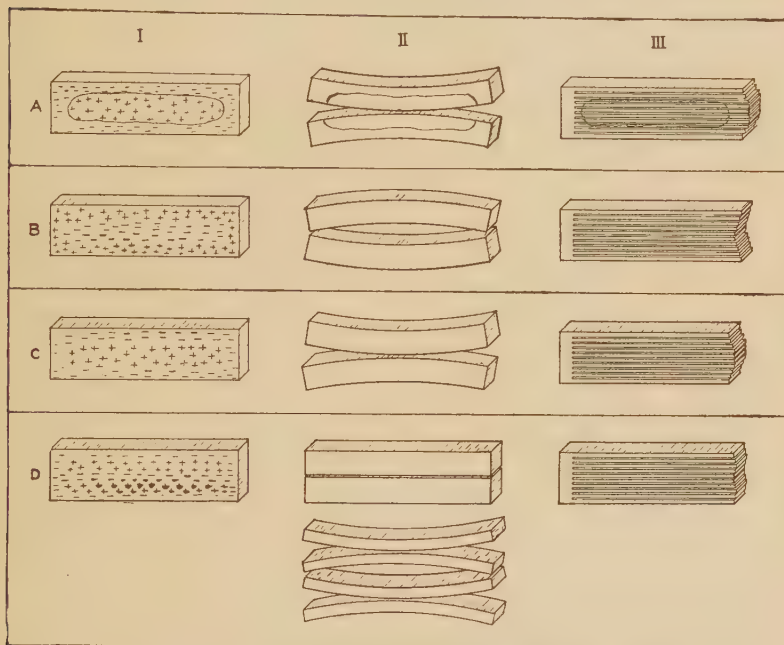


FIG. 21.—Test sections showing stages in casehardening.

A, Early stage in drying. Surface layers much drier than core and tending to shrink more. *B*, Wood uniformly dry. Surface layers set in expanded condition—casehardened; core tending to shrink. *C*, Wood uniformly dry. Surface layers set in compressed condition after excessive steaming, producing tension on redrying; core in compression. *D*, Wood uniformly dry. Set reversed in thin layer at surface after moderate steaming treatment but not in intermediate zone; stresses are balanced so that when section is resawed through the middle, pieces remain straight, but when resawed into four parts each part curves. In the drawings to the left the — indicates tension and the + indicates compression caused by differences in shrinkage. Drawings in the middle show curvature of resawed pieces caused by stresses in the wood. Drawings to the right show differences in shrinkage when section is cut into thin prongs. They are diagrammatic, since in reality the prongs would curve slightly.

may be down to 14 and 32 per cent respectively, with still no shrinkage taking place in the core. During all this time the outer layers try to shrink but cannot, or, at most, only a little toward the center, and not appreciably across the face of the board because the central portion does not shrink. This pro-

duces tensile stresses in the surface layers and compression in the center, as indicated in the test sections in Fig. 21, *A, I*, and either the surface checks or it dries in this stretched condition, that is, it becomes *set* without full shrinkage. Often both take place. It is well known that, if wood is held in a certain position while drying, it will become set and will retain the same position more or less after it is dry.

If a section is cut out of a board in this condition and then resawed through the middle, the halves will curve *outward*, as in Fig. 21, *A, II*, because of the tension present in the drier surface. Or if the section is cut into narrow strips, as in Fig. 21, *A, III*, the outer ones will immediately become shorter. This condition is a normal stage in the drying process. After such resawed material has remained in a dry atmosphere for several hours, the freshly exposed surfaces will also dry and usually will shrink more than the outer faces which have become partly set. This may cause the resawed halves to straighten out and later cup the other way.

If the drying of the lumber is continued, as it should be for most purposes, the interior also dries to below the fiber-saturation point and shrinks. It tends to shrink to the maximum possible because it is drying slowly, but the surface layers already are almost dry and *set* in a somewhat expanded condition, and in turn do not allow the interior to shrink, except just enough to close up any surface checks and to change the tension to compression in the outer layers. Figure 21, *B, I* illustrates this condition in lumber dried to a uniformly low moisture content.

If a section is cut out of a board in this condition and resawed, the halves will cup inward, as in Fig. 21, *B, II*, because of the pull the interior exerts in trying to shrink. If the section is cut into thin prongs, as in Fig. 21, *B, III*, the center prongs will immediately become shorter.

From the foregoing explanation, the definition of casehardening as being a difference in set will be more apparent.

Casehardening may occur in air drying, but usually it is more severe in kiln drying.

Air-dried lumber which already is below the fiber-saturation point may become casehardened in kiln drying if the surface dries much more rapidly than the interior, although the casehardening usually is not so severe as it may be in kiln drying

green lumber, in which the center does not shrink during the early stage of drying.

Casehardening stresses in lumber may disappear to some extent in the course of time, just as stresses do in a spring long held in tension. This probably is the chief advantage of seasoning lumber for five or seven years or longer, as is sometimes done with high-grade lumber to be used for special purposes.

34. Test for Casehardening.—In testing lumber to see if it is casehardened, follow the instructions given below:

1. About a foot or more from the end of the board to be tested cut a section about an inch wide with the grain, being careful not to include knots or other defects. It is well to note whether the board from which the section is taken is plain sawed or quarter sawed since the former probably would show more severe casehardening because it has a greater tendency to shrink in width.

2. Dry the section in warm, dry air, but not in an oven, until it is uniformly dry. This may take from overnight to forty-eight hours. This represents the condition in which the lumber probably will be used later.

3. Resaw the section. It may be sawed through the middle, in which case it represents what will happen if the lumber is resawed through the middle in the shop, or it may be cut into three or more strips, or in three, five, or seven prongs with every other prong broken out. The last method has the advantage in that the section still hangs together after it is sawed.

4. Note the extent of the cupping, especially of the outer shell, and the force required to straighten the curved pieces since these indicate the severity of the casehardening. If the section is cut into thin strips, the difference in the length of the strips when uniformly dry shows the difference in set.

If the section is cut up before it is allowed to dry out, the curvature of the prongs will be greater after it dries because the shrinkage of the inner portion of the piece will not be retarded as it dries.

It may be desirable during a kiln run to resaw the sample as soon as it is cut from the board without further drying. The cupping or difference in the length of the prongs in such a case is not representative of what will occur in the stock when it is uniformly dried, but it indicates the stresses present in the lumber at *that stage of drying*.

35. Prevention, Removal, and Reversal of Casehardening.—

Casehardening can be prevented by drying lumber in a humidity so high that the surface layers do not dry much faster than the interior. (They must dry somewhat faster so as to have a gradation of moisture which causes the transfusion of moisture from within outward.) This, however, would mean very slow drying, and hence, in commercial kiln drying and air seasoning in a dry atmosphere more or less casehardening usually occurs. In some kilns it is not possible to maintain sufficiently high humidities to prevent casehardening.

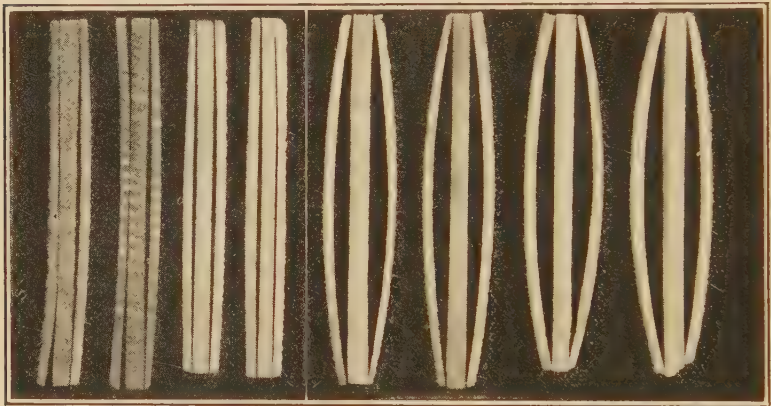


FIG. 22.—Casehardening test sections of kiln-dried western yellow pine lumber.
(*Courtesy, Forest Products Laboratory.*)

The four specimens to the left were cut before steaming; those to the right, after steaming to remove casehardening.

Whenever casehardening has occurred, it can be eliminated by subjecting the lumber to a relatively high temperature and high humidity. The high temperature in conjunction with the moisture contained in the wood makes the wood plastic, so that it can conform to the stresses, and thus eliminate them, similar to the way in which the stresses can be taken out of a spring by heating it. This is known as a conditioning treatment. The purpose of the high humidity—65 to 90 per cent—is principally to prevent drying and checking at the high temperature and to increase the moisture content of the surface of the lumber until it is equivalent to that of the center. (At the high temperatures used, the moisture also diffuses more rapidly from the center to the surface layers, and thus shortens the length of

time required to reach a uniform moisture content.) Under a condition of uniform moisture content the stresses due to differences in set are fully developed and the wood, being plastic, yields to them more readily, which relieves the stresses. (Figure 22 shows the effect of steaming western yellow pine lumber after it had been casehardened.) It has been noted that at plants where lumber was dried to a low moisture content, so that the moisture distribution became uniform, the stock was largely relieved of its casehardening without special treatment.

If a very high humidity—85 to 100 per cent—is used for a prolonged period at the end of the kiln run, then the surface layers will absorb considerable moisture and will *tend* to swell, but they *cannot* swell appreciably because the interior is not absorbing moisture equally, and so they become permanently compressed.¹ Later, as the surface layers dry out, they will shrink considerably more than they did originally because they were compressed and, hence, they will produce tension at the surface and compression further in, as indicated in Fig. 21, *C, I*. This will cause outward cupping on resawing, as illustrated in Fig. 21, *C, II*; or if the test piece is cut into prongs, the outer ones will immediately become shorter, as in Fig. 21, *C, III*. This condition is known as reverse casehardening.

It is advisable to steam woods which caseharden easily, especially thick stock, several times during the run so as to relieve the internal stresses every now and then. This, of course, is effective only after the core is below the fiber-saturation point. Steaming during the early part of the drying period of green lumber, or as long as the halves of a freshly cut test section curve outward, will not prevent or relieve casehardening.

More detailed instructions on when and how long to steam lumber and what temperatures and humidities to use are given in Chap. VII.

36. Honeycombing.—Honeycombing, or hollowhorning, is the checking of the interior of lumber as it dries. The internal stress produced in casehardened lumber when the interior tries to shrink after the surface layers are set often is so great as to pull the fibers apart. The checks so produced usually extend along the medullary rays because, as already stated, the tangential shrinkage is greater than the radial and there is a weak

¹ The surface layers may swell enough to stretch the interior so that it will check or honeycomb.

plane where the rays cross the fibers. Internal checks are shown in Fig. 23. The checks do not extend to the surface, as a rule, because the outer portion is not in tension but is in compression, although the honeycomb checks and surface checks may occasionally run together or the surface checks may deepen and broaden out toward the center while they close up at the surface. When the surface checks close up, danger of honeycombing begins. Lumber which is apt to honeycomb should be given the first steaming or conditioning treatment at this stage.

Wood rarely honeycombs along the rings, but the tangential faces of honeycombed lumber often cave in because of the



FIG. 23.—Good and bad seasoning. Stock with internal checks is said to be "honeycombed" or "hollowhorned." (Courtesy, Forest Products Laboratory.)

shrinkage in the radial direction. It is very probable that collapse of the cells in the interior of wet lumber adds to the internal stresses and accentuates the honeycombing in some kinds of lumber. Honeycombing seems to occur more easily in certain defects, as in the green "mineral streak" in maple, than in normal wood.

Neither casehardening nor honeycombing occurs, as a rule, at the end of a stick because at the end the core dries as rapidly as the faces. Therefore, to test for either casehardening or honeycombing a cut must be made some distance from the end.

Stock may not be honeycombed as it comes from the kiln, but it may honeycomb later if the interior was not sufficiently dried in the kiln. Honeycombing may also take place when the surface of dry stock absorbs moisture and swells.

37. Objections to Casehardened and Honeycombed Lumber.

The following are the objections to casehardened lumber:

1. Casehardened lumber cups when resawed; when unevenly dressed; when unevenly grooved on two sides; or even when uniformly dressed but the casehardening is not equal on the two sides.

2. The stresses in casehardened lumber may cause the interior to check, that is, honeycomb.

3. The stresses in casehardened wood weaken it even if it is not checked or honeycombed. The cracking of lumber in moderately rough handling, or the splitting of boards in a planer, may be due to some extent to stresses already present in the wood.

The following are the objections to honeycombed lumber:

1. The wood has been greatly weakened in resistance to longitudinal shear or splitting.

2. When the lumber is dressed or cut across the grain, the checks show on the exposed surfaces. The lumber may even fall apart after it is dressed.

38. Collapse or "Crimps."—It often happens in drying lumber which is very wet that what appears to be abnormal shrinkage takes place. The sides of the lumber seem to cave in in places. This phenomenon, which is known as "collapse," is due to the collapsing or flattening out more or less of the cell walls as the moisture leaves. It occurs principally in very wet redwood, western red cedar, swamp oak, red gum, cottonwood, willow, and eucalyptus, especially when they are quarter sawed. Figure 24 shows cross-sections of collapsed boards, and Fig. 25 shows thin cross-sections of collapsed and normal wood of western red cedar highly magnified. In redwood and some other species collapse occurs most easily in areas infected with decay.

The cause of collapse is explained as follows: In very wet wood, some of the cells at least are entirely filled with water. As this water leaves the cell cavities, air should take its place, but it is very difficult for air to pass through the wet cell walls, so in the absence of air the cells flatten out as the water leaves. This is similar to what happens if water is drawn out of a rubber tube without admitting air. It is not the air pressure on the outside

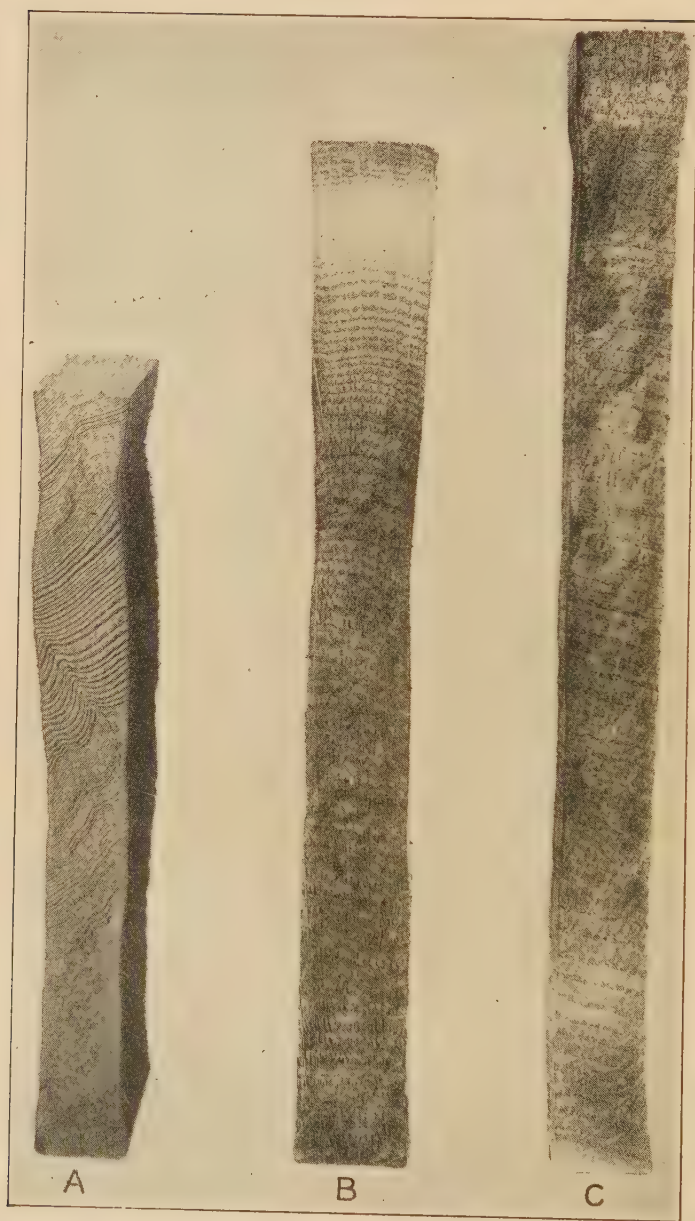


FIG. 24.—Cross-sections of collapsed redwood and oak. (Courtesy, Forest Products Laboratory.)

A, redwood; B, red oak; C, white oak. Note that the upper portion of the two oaks, which is sapwood, is not collapsed.

of the wood which is responsible for this collapse, as that at the most could be only 15 pounds per square inch, but rather the force of the water pulling the wet cell walls together as it leaves. This force is much greater than that due to atmospheric pressure.¹

Collapse takes place principally in kiln drying because when wet wood becomes hot it also becomes soft and plastic, and under such conditions collapse can take place more easily. The remedy for collapse, therefore, is to reduce the temperature in the kiln or to air dry the lumber first.

If air is already present in the cells, as in partly seasoned lumber, or in many green species, collapse does not take place

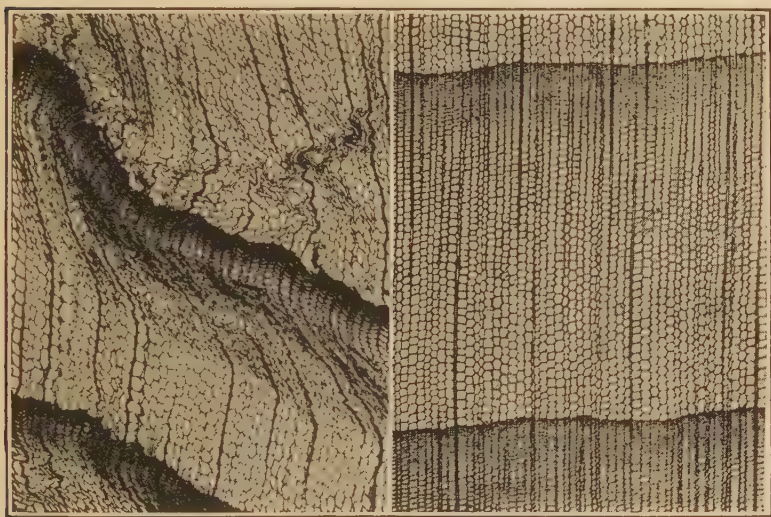


FIG. 25.—Thin cross-sections of collapsed and normal wood of western red cedar highly magnified.

because the air expands and reduces the area over which the force of the retreating moisture becomes effective in drawing the cell walls together when the water leaves. Neither does collapse take place at the ends, or near the surface, or in the sapwood, as in these parts air enters readily. Kiln-dried oak and red gum often show plump sapwood while the adjacent heartwood is shrunken and wrinkled because of the uneven collapse of the cells.

¹ The cohesive strength of water, when it can be effectually applied, has been variously estimated as being from 150 to 4,500 pounds per square inch

The phenomenon of collapse probably accounts for the apparent extensive shrinkage of some woods before the fiber-saturation point is reached, as it takes place only while the wood has a high moisture content.

It has been found possible to restore some pieces of collapsed wood to their full size by steaming them at 100 per cent humidity, or nearly so, and 180 to 200°F. until they have reached about 25 per cent moisture and then redrying them. For individual shingles the steaming must be carried on for forty-eight hours, but for shingles in packages and 1-inch or thicker lumber considerably more time is required.

CHAPTER V

TYPES OF DRY KILNS

39. Evolution of the Lumber Dry Kiln.—That outdoor drying alone was not sufficient for cabinets, furniture, and other articles for interior use or wherever tight joints are necessary was realized early in the woodworking trades. Very likely the first attempts at artificially seasoning wood consisted of stacking

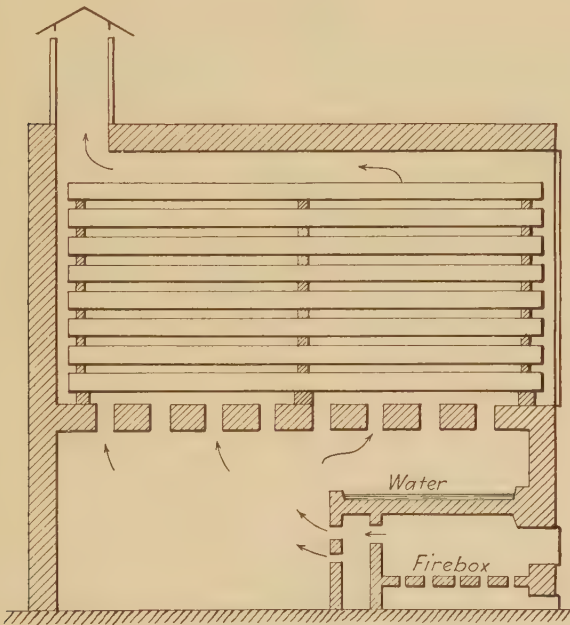


FIG. 26.—Early type of dry kiln in Europe.

lumber in open piles in a warm room—perhaps in the workshop or above the workshop—until “thoroughly dry” or until needed. The lack, however, of proper kiln-drying methods is evidenced by the open joints and checks in even high-grade furniture which has been preserved in museums or handed down as heirlooms.

Later, a separate room or special building was used for this purpose—and the dry kiln came into existence. The first kilns built in Europe consisted of a chamber with a perforated floor, beneath which a fire was built. The smoke and hot air from the fire passed through the lumber, piled openly on the floor above, and out through a vent in the ceiling. It was considered advantageous to burn green branches of the same kind of wood that was being dried, in order to get the best results.¹ Some kilns were provided with a fire box or furnace, over which a basin of water was kept to humidify the air, as illustrated in Fig. 26.

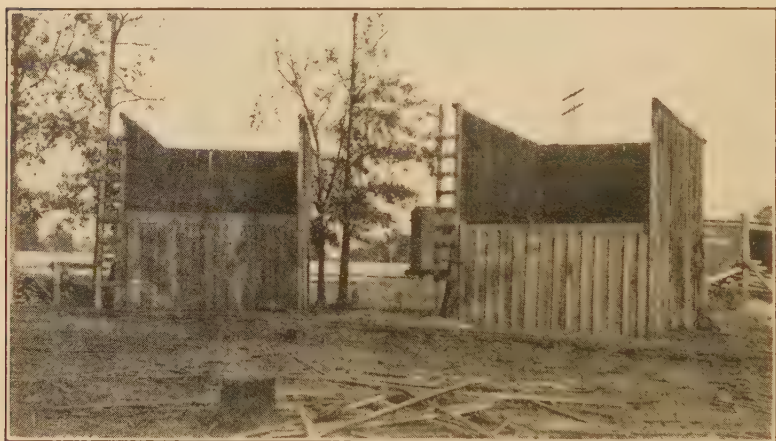


FIG. 27.—“Smoke kilns.” Lumber is piled in upper story; fire is built in lower story. (*Courtesy, Forest Products Laboratory.*)

An even less elaborate kiln, known as the “smoke kiln,” or “Arkansas kiln,” is still in use at the present time in the southern states. This kiln consists of a platform set on posts, boarded in on three sides. Lumber (pine is the principal species dried this way) is piled on the platform and a fire built underneath it, the smoke and heated gases passing through the lumber pile. Figure 27 shows a kiln of this kind. The lumber, of course, is blackened by the smoke, except where the stickers cross, but the discoloration is dressed off later.

The dry kiln, developed from these simple forms, has passed through a number of modifications. Several decades ago, when the advantages of using moist air in kiln drying began to be

¹ FITZGERALD in “Timbers of the World” by ALEXANDER HOWARD, The Macmillan Co., London, 1920.

appreciated, manufacturers of certain kilns obtained considerable advertising by calling their kilns "moist-air" kilns. These did not differ fundamentally in construction from other kilns, but rather were equipped with some comparatively simple means for maintaining more or less moisture in the air.

The introduction of vertical stacking, of various means of artificially promoting circulation, and the use of condensers and superheated steam all have been stages in the development of lumber dry kilns. Kilns having reversible circulation and automatic control apparatus regulated by a clock may be said to be the latest development in the mechanical construction of lumber kilns.

40. Classification of Kilns.—Numerous makes of kilns are on the market, each designed along special lines with one or more characteristic features, but they all fall into two classes, as far as the method of operation is concerned, namely, the progressive and the compartment. Both classes of kilns have been in use for many years. Each has its own field of usefulness. The progressive kiln finds its greatest field of usefulness at the sawmill, planing mill, and factory where large quantities of easily dried stock are turned out continuously, while the compartment kiln finds favor at the mill or factory where different kinds of lumber, each in comparatively small quantities, or woods difficult to dry, are handled, or wherever refined drying is to be done. Progressive kilns are adapted for drying 1-inch pine, spruce, fir, hemlock, and other easily dried woods. Compartment kilns are more desirable for drying green hardwoods, especially kinds which are difficult to dry, such as oak, beech, and eucalyptus in thick sizes, and for high-class work. Between these two extremes there is a wide field in which the choice of the type of kiln depends upon a number of other considerations. These are discussed later in this chapter and in Chap. X.

Although probably just as much lumber is now being dried in progressive kilns as in compartment kilns (because of the large amounts of softwoods dried in progressive kilns at the mills), the tendency is toward a greater use of compartment kilns.

Dry kilns may also be classified, as to the method of getting rid of the excess moisture in the air, into the ventilating and the condensing types; or, as to the method of bringing about movement of the air, into the natural-draught and forced-draught types.

41. Plan of Progressive Kilns.—Progressive kilns consist of a long chamber, usually from 100 to 150 feet in length, although some progressive kilns only 60 feet in length and others over 300 feet in length have been built. Because of their comparatively great length, kilns of this type are often referred to as tunnel driers. Doors and approaches or loading and unloading platforms are provided at both ends. The lumber is put in at one end, known as the green or charge end, and is progressively moved forward from time to time toward the dry or discharge end, where it is taken out when dry enough. The atmospheric conditions remain the same in each part of the kiln except as influenced by outside conditions. These kilns are always provided with trucks on which the lumber is stacked and moved forward. As a rule, the tracks on which the trucks run slope



FIG. 28.—Interior view of a progressive kiln. (Courtesy, Standard Dry Kiln Co.)

slightly downward toward the dry end, so that the trucks can be moved along more easily. The dry end usually contains the hottest and driest air. Kilns of this type usually are operated on a time schedule. Figure 28 shows a progressive kiln.

42. Plan of Compartment Kilns.—Compartment kilns usually are from 18 to 50 feet in length, although some have been constructed over 100 feet long. In the compartment type the lumber remains stationary until it is dry, the atmospheric conditions being changed to suit the needs of the lumber as the drying progresses. On account of this method of operation, kilns of this type have also been designated as "stationary" kilns in contrast with progressive kilns. When the lumber is dry, the entire charge is removed. Doors and approaches are necessary only at one end, although for convenience some of the longer compartment kilns load from one end and discharge from the other.

The shorter kinds are not necessarily provided with trucks, the lumber being piled on the operating floor or on horses. Small kilns of this kind are often called "box" or "pocket" kilns. Figure 29 illustrates a compartment kiln.

43. Progressive and Compartment Kilns Compared.—No flat statement can be made as to which is the more efficient in drying lumber, the progressive or the compartment kiln. The kind and quantity of lumber to be dried, the purpose for which it is to be used, and local conditions must be taken into consideration. The relative merits of these two types are given here to help in selecting the more suitable type for any given operation.

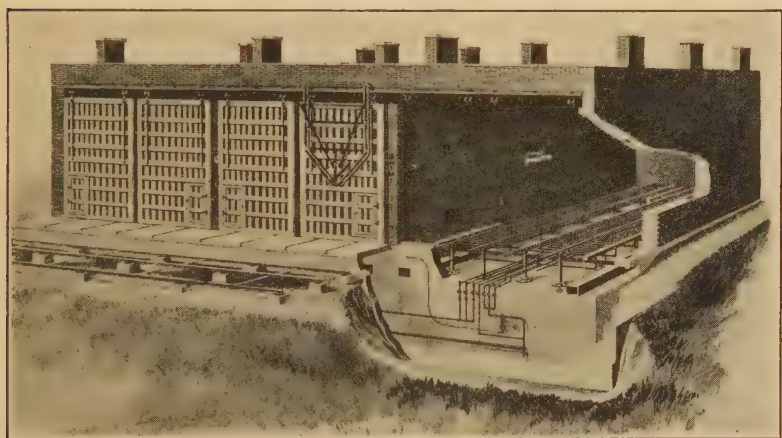


FIG. 29.—Interior view of a compartment kiln. (Courtesy, Standard Dry Kiln Co.)

The advantages of progressive kilns are:

1. The cost of construction is less than that of a larger number of shorter compartment kilns of the same total capacity because there are fewer end walls, fewer fittings, especially in the heating coils, and fewer approaches.

2. Less skill is required to operate them because the conditions are not changed from time to time; instead, the lumber is moved forward to more severe conditions.

3. The output usually is more steady. A few truck loads are taken out each day or so, keeping the shop or shipping force busy; in compartment kilns a whole kiln charge is ready at one time. This makes the output of compartment kilns "jerky," unless each unit is comparatively small, and more dry storage

room is required so as to accommodate a charge when it is removed.

4. For drying green lumber the progressive kiln with longitudinal circulation can be made to have the highest heat efficiency of any hot-air kiln. If the air which enters at the dry end has a comparatively high temperature and low humidity, and leaves at the green end at a much lower temperature and practically saturated, all the evaporation that may be expected from it has been accomplished. On the other hand, in a compartment kiln, or in a progressive kiln in which air-seasoned lumber is being dried, the air which is expelled leaves in an unsaturated condition, and, toward the end of the run in a ventilated compartment kiln, at a comparatively high temperature, taking away a lot of heat which was not used in drying the lumber.

The advantages of compartment kilns are:

1. Since compartment kilns usually are short and need be opened at only one end, they can be built in cramped quarters. One end may be built against a building or close to the property line. This cannot be done with progressive kilns.

2. Small quantities of lumber may be dried at a time, and intermittently, while a progressive kiln should be full and operated continuously to obtain proper drying conditions.

3. The stock can be sorted out so that different species, or different thicknesses, or lumber in various stages of air seasoning can be put in different kilns, while in a progressive kiln it is often necessary to put several classes of material through under the same conditions.

4. The large doors need not be opened during the drying operation. A small side door is usually provided through which the kiln may be entered. In the progressive type the large doors at both ends must be opened every day or so to take out lumber and add fresh stock. This upsets drying conditions. Furthermore, it is often necessary to allow the kilns to cool off repeatedly so that the workmen can go in and move the truck loads forward.

5. Because conditions must be changed from time to time, there is better opportunity for properly regulating conditions in the compartment kiln to suit the exact needs of the lumber in all stages of drying. Therefore, better results can be obtained with a compartment kiln, especially in the drying of difficult species

6. Compartment kilns are not influenced so much by the wind as progressive kilns, especially progressive kilns with longitudinal circulation.

7. The charge in a compartment kiln can be steamed, cooled off, and even stored in the kiln if it is not in immediate demand, without affecting any other stock. In progressive kilns it usually is impossible to steam lumber properly at any one stage of drying to relieve casehardening stresses when that is desirable.

44. Ventilating and Condensing Kilns.—By ventilating kilns, as used in this text, is meant all kinds of kilns in which more or less fresh air is taken in from outdoors and a certain amount of moist air is expelled. This includes both natural-draught and forced-draught kilns, although among kiln men there is a tendency to include under “ventilated kilns” only those with natural draught and to refer to others as “blower kilns.” The restriction of the use of the word “ventilated” to a natural movement of air is not consistent, however, with its use in respect to buildings occupied by living beings, in which the air is often moved by fans.

Inlet and outlet ducts and flues are provided in nearly all ventilated kilns, their location depending upon the type and the make of the kiln, as will be described later. In some kilns of this type no openings are provided for admitting fresh air or expelling moist air, the “ventilation” taking place through cracks and other small openings.

In condensing kilns the same air is used over and over again (except what leaks out), and some means is provided for removing part of the moisture from the air.

Both ventilating and condensing kilns may be of the progressive or of the compartment type.

45. Kinds of Progressive Kilns.—The various makes of progressive dry kilns differ principally in the manner in which the air is taken in, how it circulates in the kiln, and how it is expelled, although there are also some differences in the heating systems. In order to discuss these differences, it is desirable to describe the ventilating and condensing kilns separately.

(a) *Ventilating Kilns.*—In almost all progressive kilns of the ventilating type the fresh air comes in at the dry end underneath the lumber. It may enter through perforated ducts located at the bottom of the kiln and extending from the dry end to about the middle of the kiln (Fig. 30), or the operating floor may form the roof of a large tunnel under the dry end,

in which case the air enters the kiln chamber through openings in the floor, or there may be no floor. In the last two cases the fresh air usually is prevented from moving under the green end by a partition across the bottom of the kiln about halfway between the two ends; in some other progressive kilns of this kind the entire space under the tracks is open.

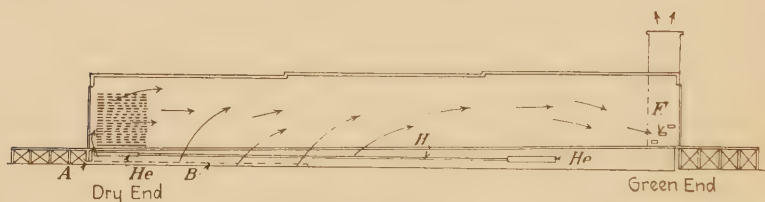


FIG. 30.—Natural-draught progressive kiln with longitudinal circulation and cross piling.

A, air inlet; *B*, perforated duct; *H*, heating coils; *He*, headers; *F*, openings to vertical flues. Arrows indicate direction of circulation.

The fresh, dry, heated air strikes the driest lumber first. From the dry end it passes toward the green end, picking up moisture and becoming cooler on its way. The air passes out of the kiln chamber at the green end, through openings in the walls, either beneath the level of the tracks or slightly above them, which

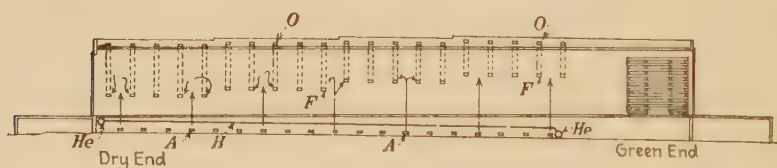


FIG. 31.—Natural-draught progressive kiln with vertical-lateral circulation and end piling.

A, air inlets; *F*, openings to flues in side walls; *O*, openings of flues above roof; *H*, heating coils; *He*, headers.

connect with vertical flues. In this way the green lumber is subjected to lower temperatures and higher humidities than the dry lumber.¹ Almost all kilns of this type depend upon the natural draught in the chimneys at the green end to produce a change of air within the kiln, although some are provided with

¹ Some progressive kilns are hotter at the green end, but this arrangement is not consistent with the best methods of drying lumber, although for drying certain fruits and vegetables the best results are obtained in this way. Even though the air is hotter at the green end, the product dried may not be any hotter than at the dry end because of the cooling produced by the rapid evaporation at the green end.

blowers. The Welch kiln (described on page 94) is equipped with a steam jet in the intake duct to increase the amount of fresh air entering the kiln. The movement of the air from the dry end toward the green end is referred to in this text as "longitudinal circulation."

The Emerson, Morton, Grand Rapids, and Thermo-Myst progressive kilns are designed for transverse instead of longitudinal circulation. Exits for the leaving air are provided in the side walls at or near the ceiling, or at the bottom of the kiln, at intervals along the full length of the kiln except at the green end (see Fig. 31).

The heating pipes in progressive kilns are underneath the tracks, except in the blower kilns, but they do not extend the full length of the kiln as a rule; they extend only one-half or two-thirds of the length, leaving the green end without direct heat (see Figs. 28, 30, and 31). In some progressive kilns, the heating coils extend underneath the green end also, but the steam enters at the dry end, making that portion of the kiln hotter. In others, the steam enters at the green end of the coils, making that end hotter unless an additional amount of piping is placed at the dry end.

(b) *Condensing Kilns*.—Comparatively few progressive kilns are equipped with condensers. When condensers are installed in such kilns, they are also equipped with blowers to recirculate the air. The condenser and blower together with the heater usually are located in a room adjacent to the kiln proper. The air is drawn from the green end by the fan and is blown through the condenser and heater, from where it is returned to the dry end of the kiln. In the old Sturtevant "Common Sense" progressive kiln, which is of this type, the air enters the kiln chamber through openings in the floor at the dry end and is withdrawn through similar openings in the floor at the green end. The American Blower Co. installs progressive kilns with or without condensers. In the latter case only part of the air is recirculated.

46. Kinds of Compartment Kilns. (a) *Ventilating Kilns*.—Compartment kilns of the ventilating type probably are the most common. In these kilns fresh air usually enters the drying chamber through perforated ducts at the bottom of the kiln, as is illustrated in Fig. 32. In the Grand Rapids and Standard kilns, however, the air enters the kiln chamber near the ceiling,

coming up through vertical flues within the side walls, as in Fig. 33. The fresh air enters these flues from a chamber at the base of the kiln or from some adjoining warm room or shed where weather conditions are less fluctuating than outdoors.

In almost all compartment kilns, depending for circulation on natural draught, the air exits are located in the side walls where they connect with vertical flues, or stacks. Usually the air exits in the side walls are located nearer to the floor than to the ceiling (Fig. 32); in some kilns they are even located below the

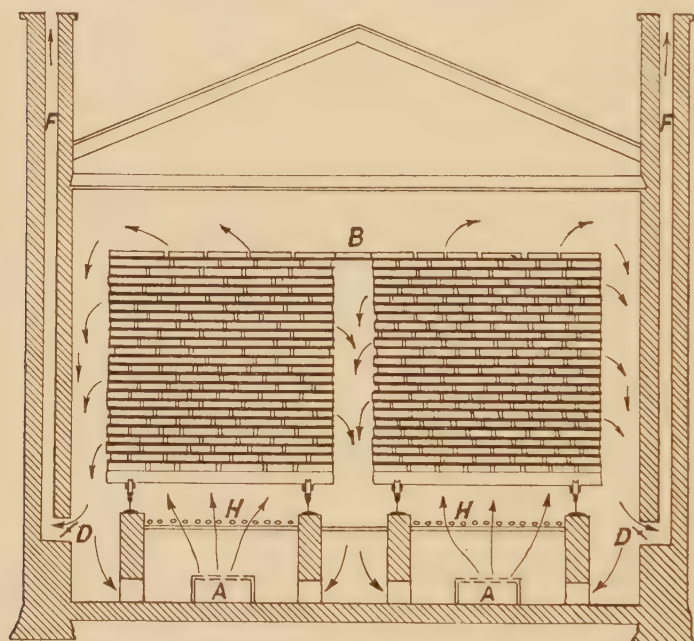


FIG. 32.—Cross-section of natural-draught compartment kiln with end-piled lumber, the stickers running crosswise.

A, entering air ducts; *F*, leaving air flues; *D*, dampers; *H*, heating coils; *B*, baffle to prevent short-circuiting of air currents.

level of the operating floor. In the Emerson kiln, however, the air leaves the kiln chamber near the ceiling and then goes downward within the walls to about halfway from the ceiling to the floor and then outward if in an exposed wall, or upward to the roof if in a wall between two kilns.

In some kilns the air leaves through ventilators in the ceiling. In the Grand Rapids kiln the leaving air enters ducts at the bottom of the kiln, underneath the heating pipes. These ducts

connect with vertical flues in one of the side walls. A few heating pipes are located in the vertical flues, or stacks, to increase the draught (see Fig. 33).

Some ventilating compartment kilns rely on a natural movement of the air for circulation, but the American Blower Co., B. F. Sturtevant Co., Northwest Blower Kiln Co., Moore Dry

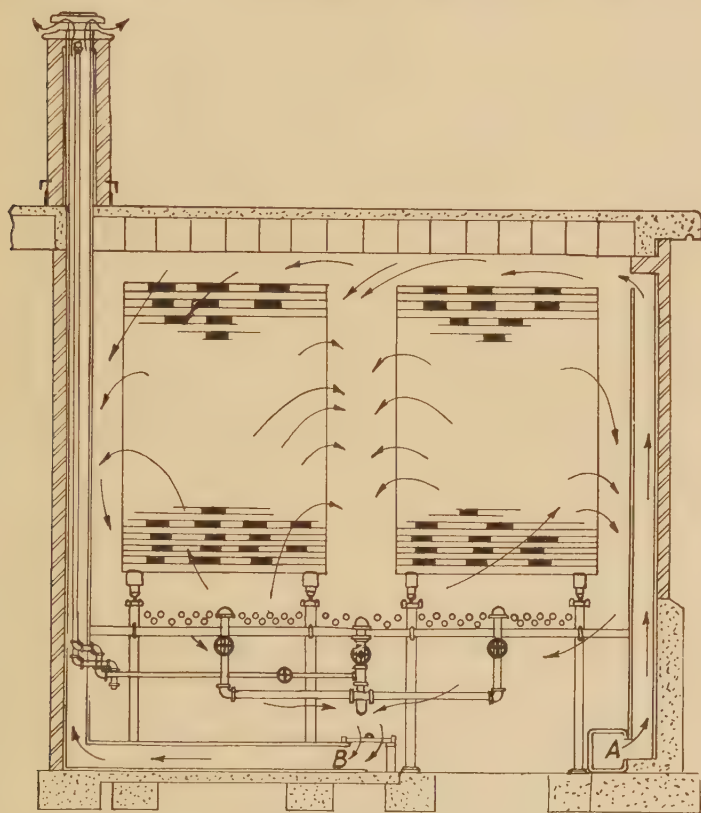


FIG. 33.—Grand Rapids vapor kiln from a drawing by the Grand Rapids Veneer Works.

Kiln Co., and Cutler Desk Co. make compartment kilns equipped with blowers which take in fresh air and expel moist air, although part or all of the air may be recirculated.

The heating pipes in ventilating compartment kilns usually are underneath the lumber, except in some of the blower kilns and in the Nichols kiln. In the latter the steam pipes are within the lumber pile. The heating pipes are in layers in a

metal framework, which can be expanded vertically by hydraulic lifts somewhat like a bellows, and the lumber taken out and fresh lumber put in place. When the framework is filled, it is let down. The lumber is then held rigidly in place. The lumber does not rest on the heating pipes; it rests on metal slats. No other stickers are required.

In the reversible-circulation internal-fan kiln, several fans driven by external motors are located within ducts at the bottom of the kiln. By reversing the rotation of the fans, the direction of circulation through the lumber piles can be reversed. This materially accelerates the drying of the kiln charge since it obviates the lag in drying which occurs in one-direction circulating kilns at the places where the air leaves the lumber piles.

Three rather unusual kinds of compartment kilns should be mentioned here, namely, the "dry-air" kiln, the boiling kiln, and the superheated-steam kiln.

In "dry-air" kilns no attempt is made to regulate or to retain a certain humidity around the lumber, although a slight amount of moisture is always present in the air. Such drying methods are apt to produce poor results unless the drying is very slow. Few kilns working on this principle are in use. The smoke kilns mentioned at the beginning of this chapter may be classified as such. Obviously, only very low temperatures can be maintained in these kilns on account of the fire risk involved; therefore, the drying is slow. Some lumber dried in this way has been reported to be of excellent quality, as far as its behavior in manufacture is concerned, although it is darkened on the surface.

As a general rule, the slower the drying the less injury the lumber is apt to receive. In almost all commercial practices it is very important that the drying be rushed, and under such conditions moist air is absolutely essential to the drying.

Drying at a high temperature with only slight external circulation is known as the oven or boiling process. Almost any kind of a kiln with enough heating capacity may be used. The kiln is closed tight, except for small outlets, to allow the escape of excessive moisture in the air, and the lumber is heated to from 190 to 230°F. At the high temperatures employed, the moisture leaves the lumber quickly. The air is kept moist because the kiln is fairly tight, and, therefore, little checking and casehardening result. This method can be used only with certain kinds of

wood, principally conifers, which are not seriously injured by the high temperature. It is used to some extent in the Pacific Northwest in drying Douglas fir and other conifers, to reduce their shipping weight. The internal circulation in a kiln of this kind is not rapid, and the lumber must be piled fairly open in order to supply the necessary heat throughout the piles. This differs from the superheated-steam kiln described below in that somewhat lower temperatures are used and not all the air is replaced by steam.

So far, kilns in which air is the principal heating medium have been discussed. Other vapors or gases may be used, but the only other practical one is superheated steam. Ordinary steam as it comes from a boiler is saturated and cannot take up any more moisture; in fact, it will precipitate moisture on the slightest cooling. But if this steam is heated to a higher temperature after it leaves the boiler, or if it is allowed to expand, as when it escapes to the atmosphere, it becomes "superheated," and then it may be cooled somewhat before any condensation takes place. In fact, superheated steam will pick up moisture if the opportunity is afforded. Therefore, it can be used for drying lumber and other commodities which will not be seriously injured by temperatures above 212°F. since at atmospheric pressure "steam," in the ordinary sense of the word, does not exist at less than 212°F., and superheated steam must necessarily be hotter. In kilns operating on this principle the steam is superheated either outside of the kiln proper and forced through the kiln by means of a blower, or dry, high-pressure steam is admitted into the kiln by means of steam jets and becomes superheated as it expands, heating coils usually being used to increase the superheat.

Obviously, the superheated steam must have a temperature considerably above 212°F. in order to pass through the lumber before it is cooled to that temperature, or it must pass through the lumber at a very high velocity.

Several kinds of high-velocity, low-superheated-steam kilns have been developed. In these kilns the steam enters the kiln through jets at a high velocity, and thus passes through the lumber quickly. Therefore, the steam need not be greatly superheated in order to pass through the lumber before it loses its superheat, and lower temperatures can be used than in superheated-steam kilns in which the circulation is sluggish.

The superheated-steam method dries lumber very rapidly, but it requires great quantities of heat since only the superheat in the steam is made use of, except in the initial heating of the lumber, when the latent heat of steam (explained in Chap. VI) is also made use of. This process is practical only where fuel is cheap. Furthermore, this method can be used on only a very limited number of species because most woods will be injured by the high temperatures. The boiling and superheated-steam kilns are placed under the category of "ventilated kilns" because the excess moisture escapes to the atmosphere.

(b) *Condensing Kilns*.—A number of kinds of condensing compartment kilns, which differ in methods of recirculating the air and getting rid of the moisture, are in use:

1. *External Condensing-coil Kiln*.—In kilns of this kind the blower, condensing coils, and heating coils are adjacent to the kiln proper. A number of compartments are sometimes connected with the same blower, although this is poor practice.

It has been found that in some installations of this kind enough condensation takes place on the walls of the kiln and in the ducts leading to the fan room so that the condensers are not necessary, at least not during part of the run.

2. *Internal Condensing-coil Kiln*.—Some kilns are provided with condensing coils within the kiln chamber. The water in these coils is kept cooler than the air in the kiln, and as a consequence they "sweat," or condense part of the moisture. By regulating the temperature of the condensing water, either by mixing hot and cold water or by changing the rate of flow of water through the coils, the amount of condensation, and hence the humidity in the kiln, can be controlled.

A difficulty encountered in the use of condensing coils in some compartment kilns is that the circulation is not so rapid as may be desired, especially in the early stages of the drying period when good circulation is most essential. The circulation usually depends entirely upon the rising of the hot air and the falling of the cool air within the kiln.

3. *Water-spray Condensing Kiln*.¹—In this kiln, condensation, and hence the humidity, are regulated by sprays of water arranged in rows along the side walls of the kiln from end to end (Fig. 34) or by one row of sprays in the middle. The spray cham-

¹ Invented and patented by H. D. TIEMANN, of the U. S. Forest Service. The patent is dedicated to the public.

ber extends about 4 feet below the level of the operating floor and is drained by a gutter.

The heating pipes are located underneath the lumber. The air circulates upward and laterally through the pile, toward the spray chambers, where it is drawn downward by the sprays. From the spray chambers the air passes through openings to the space under the heating coils and then upward and is

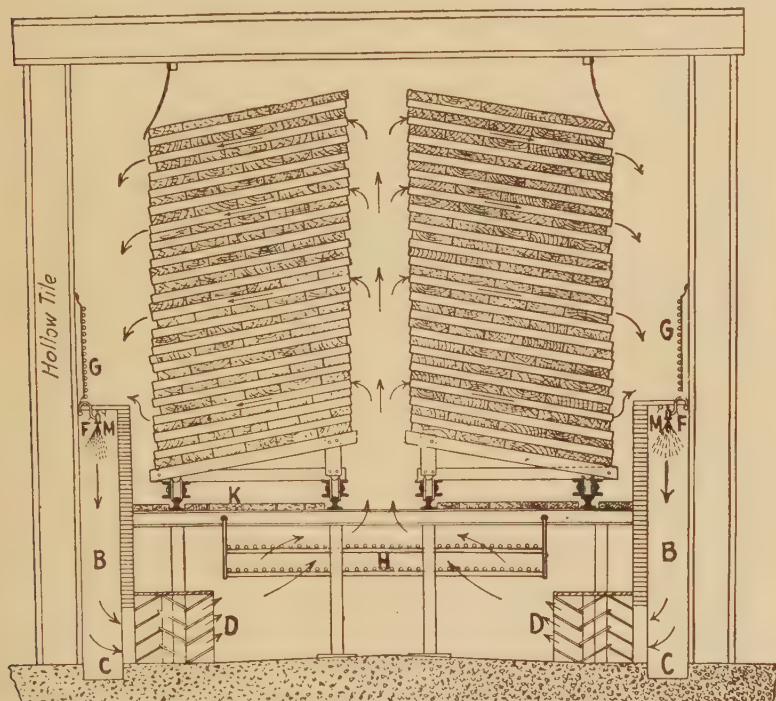


FIG. 34.—Diagrammatic section of humidity-regulated, water-spray dry kiln with inclined piling of lumber. (From *United States Department of Agriculture Bull.* 509.)

H, heating coils; *G*, condensing coils; *F*, water sprays; *B*, spray chambers; *D*, baffle plates; *C*, gutters; *M*, steam spray pipes with holes on lower side. Lumber may also be flat piled.

reheated, and recirculated. In order to prevent any mist from being carried along and raising the humidity, baffle plates are placed between the spray chamber and the heating chamber (see Fig. 34).

Since all the air must pass through the water sprays, its humidity as it recirculates can be closely regulated by regulating the temperature of the spray water. For this purpose automatic water mixers may be installed. The water is used over

again as far as is practicable. The water sprays also increase the circulation.

In this kiln, therefore, the circulation, temperature, and humidity are independent of each other, and any desired condition for drying lumber can be obtained within the kiln.

4. Curtain Kiln.—This kiln, as originally designed, consisted of four canvas-curtain walls and a roof of canvas or other material

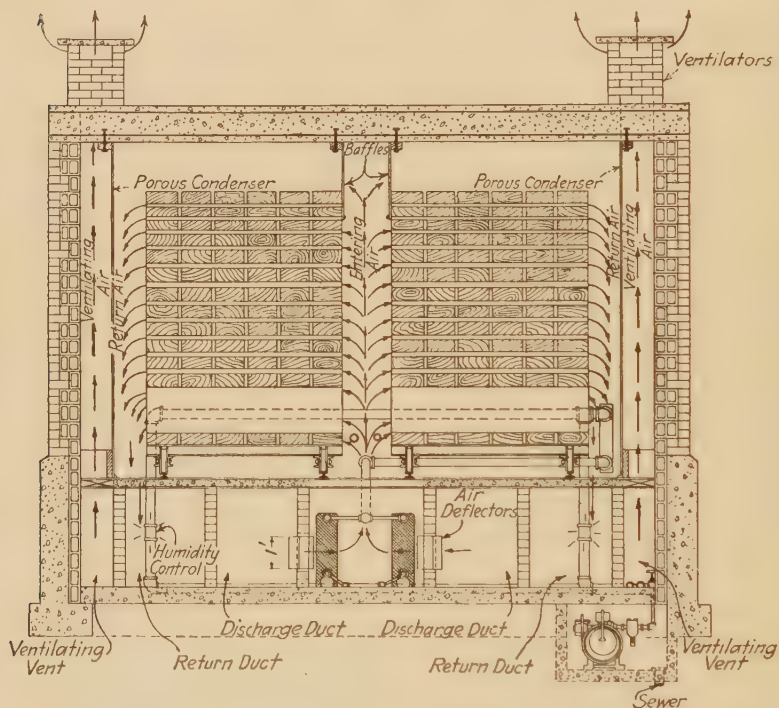


FIG. 35.—Transverse section of curtain kiln. (Courtesy, Culler Desk Co.)

set up within a building. The heating coils were located along one wall, and the air was recirculated by means of office fans set on the floor. As the air came in contact with the cooler canvas walls, it deposited some of its moisture on them, this moisture being picked up by the air outside of the kiln.

A later model of this kiln, designed for outdoor construction, has outside walls, roof, etc. made of hollow tile or other substantial material. About 1 foot from each of the two side walls there is an inner canvas wall. The moisture which evaporates

from the lumber within the kiln chamber is condensed on the canvas walls, from which it is removed by air circulating upward between the outside wall and the canvas. This air enters at the bottom of the side chambers from outdoors and passes out through ventilators in the ceiling without coming in direct contact with the lumber.

Within the kiln chamber the air is recirculated by an external blower. The heating system is in the middle of the kiln, below the level of the operating floor. Figure 35 shows a diagrammatic section of this kind of kiln.

47. Ventilating and Condensing Kilns Compared.—The decision as to whether a ventilating kiln is more economical to operate than a condensing kiln depends upon so many factors governed by local conditions that no general statement can be made.

Ventilating kilns as a class are cheaper to construct than condensing circulating kilns built of the same material because the latter must be provided with special equipment for getting rid of the moisture in the air.

But condensing kilns are more independent of outdoor conditions. The same air can be used over and over again, and, therefore, the temperature and the humidity can be controlled much better. The more difficult the lumber is to dry the more important this feature becomes.

In considering which is cheaper to operate, a ventilating kiln or a condensing kiln, the amount of degrade produced in the kiln should always be taken into consideration. Other important factors are cost of fuel, cost of water for condensing purposes, interest on investment, taxes, insurance, cost of repairs, and the type of man required to operate the kiln.

If a battery of kilns dries \$500 worth of stock in a day, or \$150,000 worth in a year, to obtain the lowest possible amount of degrade in the kiln may be of more importance than the operating cost, interest, and depreciation, or the cost of employing an intelligent man to operate the kilns.

48. Veneer Driers.—Thin veneer is usually dried by an entirely different process from that required for lumber, although thick veneer is often stacked on trucks and run into a kiln, where it is dried like other forms of lumber. Tracks are not always provided, the trucks being run along on the floor. Figure 36 shows a longitudinal section of a "tunnel" or progressive veneer kiln with a pressure blower at the dry end. The curtains in

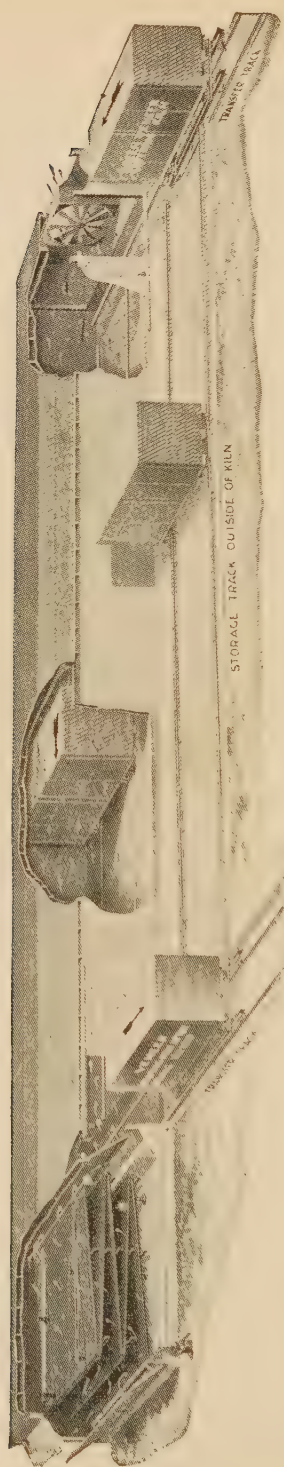


FIG. 36.—Longitudinal section of progressive, suction-fan, veneer kiln. Patent applied for by Moore Dry Kiln Co.

the kiln prevent short-circuiting of the air over the trucks. Since a truck load of veneer is comparatively light, it is necessary to add weight to the top of the pile or to tie the top cross-pieces down in order to keep the stock straight as it dries.

There are two principal types of special veneer driers on the market. One consists of a chamber about 50 to 100 feet long, 8 feet high, and 6 to 13 feet wide, usually made of sheet metal. This chamber contains live rollers, or several wide, endless steel link belts placed one above the other so that the lower surface of one touches the upper surface of the one beneath it. The

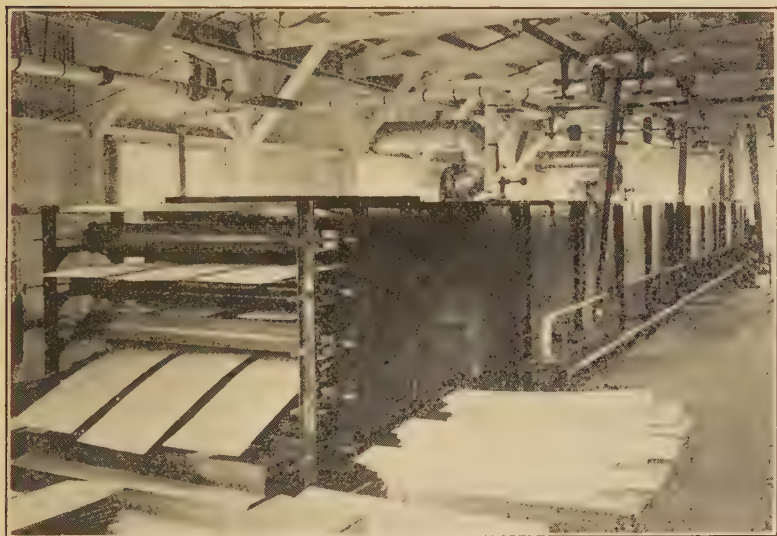


FIG. 37.—Endless conveyor veneer dryer. (Courtesy, Proctor and Swartz, Inc.)

veneer is placed on these rollers or belts at one end and is carried forward through the chamber at a speed which can be regulated to suit the requirements of the material. A current of hot air, the temperature and humidity of which can be regulated, is passed through the drier. Figure 37 illustrates a drier of this type.

Another type of drier consists of a series of horizontal or vertical hollow plates close together, so manipulated by power that they separate about an inch every five seconds to five minutes—a process known as “breathing.” The plates are kept hot by steam in the interior. The sheets of veneer are placed

between the hot plates, when they are separated, and as the plates close up they come into direct contact with the veneer, heating it and at the same time keeping it flat. The next separation of the plates allows steam to escape and shrinkage to take place. This kind of veneer drier is illustrated in Fig. 38.

The drying of veneer by these methods can be accomplished in from three to ninety minutes.

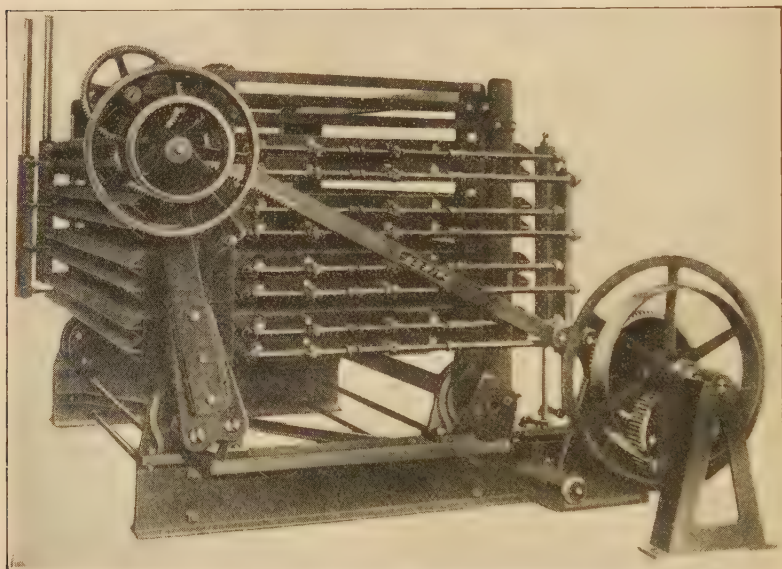


FIG. 38.—Hot plate veneer redrier. (Courtesy, Merritt Manufacturing Co.)

49. Brief Description of Commercial Dry Kilns.

AMERICAN BLOWER CO., Detroit, Mich.:

Progressive kilns.—

Ventilating type:¹

Forced Draught.—Circulation is produced by a fan or blower located in an adjacent space. The heating coils are all concentrated in the fan house and may be located at the inlet or outlet of the blower, depending upon the space available.

Air enters the dry end of the kiln through slots in the floor and passes to the green end, where it sinks underneath the floor and is forced out through vent openings, or part of the air may be recirculated to the blower in order to obtain air of the proper humidity.

¹ See page 77 for definition of ventilating kiln.

Means may be provided for moistening the air either by water sprays or by steam jets. Automatic temperature control may be added for regulating the steam supply to the heating coils. Automatic humidity control may be added for regulating the quantity of recirculated or fresh air admitted to the circulating system and for controlling the water sprays or steam jets where they are installed.

Compartment or "apartment" kilns.—

Ventilating type:

Forced Draught.—Circulation is produced by a blower or fan located in an adjacent space. The heating coils are also located in the adjacent space and may be placed at the fan inlet or outlet, as may best suit conditions.

Air enters the kiln through ducts at or beneath the level of the operating floor along the middle of a double-track kiln or along a side wall in a single-track kiln. The air passes out of the kiln chamber through ducts near the bottom of the kiln along both side walls of a double-track kiln or along one side wall in a single-track kiln. This air may be recirculated or part of it may be allowed to escape to the outside air.

Automatic temperature control may be used for regulating the steam supply to the heating coils. Automatic humidity control may be used for regulating the quantity of fresh or recirculated air, or for controlling the water sprays or steam jets. Steam sprays may be used for steaming the contents previous to drying.

THE STANDARD DRY KILN CO., Indianapolis, Ind.

Progressive kilns.—

Ventilating type

This company builds two styles of progressive kilns. Both have horizontal heating coils underneath the tracks. In one style the coils run the full length of the kiln. In the other, and newer, style part of them extend one-third and part two-thirds of the distance toward the green end, but none extends all the way. At the green end there is a set of steam-spray apparatus for steaming and providing humidity. In some kilns special sprays are placed at other points, including the dry end.

Fresh air enters through perforated ducts on the floor under the coils. These ducts extend from the dry end to a point at about one-third the length of the kiln. The air passes around and through the lumber piles from the dry end to the green end, where outlets (the number varying with the size of kiln) are located in each of the side walls at various heights above the operating floor. These outlets connect with vertical flues extending above the roof. Incoming and outgoing ducts are provided with dampers adjusted from outside the kiln.

Compartment kilns.—

Ventilating type

End Piling.—Horizontal or vertical heating coils are located underneath the lumber the full length of the kiln. The coils are divided into groups with separate controls.

Air enters horizontal ducts located along the side walls of the kiln at the ground level. These ducts connect with vertical flues in the side

walls, and these flues open into the kiln on both sides of the chamber near the ceiling. Air outlets are located in both side walls, at various heights above the floor, and open into vertical flues which extend above the roof. The inlets and outlets are staggered. The change of air in the kiln can be controlled from outside the kiln by dampers in both incoming and outgoing vents. Underneath and above the lumber, running the full length of the kiln, is the steam-spray apparatus for steaming and providing humidity. It is equipped with patent spray nozzles.

Cross-piling.—In general, the building construction for this kiln is the same as the regular type of compartment kiln, but this construction is designed primarily for the crosswise piling of the lumber.

The heating coils are of the return-bend type and located directly below the center of each truck of lumber and extend to within approximately $2\frac{1}{2}$ feet of each side wall. There is an independently controlled coil for each car of lumber and a special and independently controlled coil at each door. The kiln is designed to have the hot air rise within each truck load and go down between the trucks.

There are sprays for humidifying purposes and independently controlled steam jets (primarily designed to accelerate the circulation) located across the kiln and between the various coils and directly below the space left between the kiln trucks.

While each heating coil and steam jet has its own independent control, the entire heating system as well as steam-jet system are also controlled by master valves located outside the kilns, and can further be controlled by thermostats.

Condensing type:

The Standard Dry Kiln Co. builds water-spray kilns according to original designs by Mr. Tiemann with either side or center spray chambers.

NATIONAL DRY KILN CO., Indianapolis, Ind.

Progressive kilns.—

Ventilating type:

The heating pipes are located under the tracks in vertical or horizontal rows. They are connected to the steam main at the charging or discharging end of the kiln, the condensation being drawn off at the other end. The coils are of variable length, part of them extending one-half of the length of the kiln, and part of them three-quarters of the length of the kiln, the greater part of the radiation being located at the dry end. The coils are divided into six or eight units, each being independently valved. Fresh air is taken in through perforated ducts under the coils extending from the dry end to the center of the kiln. Seven or eight exits for the leaving air are located in the side walls at the green end at various elevations above the level of the tracks. Here they connect with vertical flues, or stacks. Incoming and outgoing ducts are provided with dampers to regulate the draught.

Compartment kilns.—

Ventilating type:

The heating pipes are located below the operating floor in vertical rows extending the full length of the kiln. The coils are divided into six or eight units, each of which is independently valved. Fresh air enters through the horizontal perforated ducts under the steam coils. These ducts extend the full length of the kiln. The air outlets are in the side walls at intervals between the ends and at various heights above the floor level. Here they connect with vertical flues. Dampers are provided for both incoming and outgoing air vents. An automatic regulating apparatus, known as the "Moistat," which varies the wet-bulb temperature between wide, adjustable limits (thus automatically following the intermittent steaming process of drying), may be obtained from the company.

Combination ventilating and condensing type:

The National Dry Kiln Co. will build to order a combination of its ventilating compartment kiln and the water-spray kiln.

MORTON DRY KILN CO. (taken over by the National Dry Kiln Co.;
kilns no longer made except by special request)

Progressive kiln.—

Ventilating type:

The heating coils are located under the tracks and extend about three-fourths of the distance from the dry to the green end. The fresh air enters through the openings at intervals along the side walls, except at the green end, below the level of the heating pipes. It leaves through openings in the side walls at increasing heights above the floor from the dry toward the green end as far as the heating coils extend. At the green end beyond the heating coils there is no provision for air entering or leaving the kiln. The air outlets connect with vertical flues within the side walls which extend above the roof. The Morton progressive kiln resembles the Emerson progressive kiln in not being designed for longitudinal circulation. Figure 31 approximately represents the construction of this kiln.

Compartment kilns.—

Ventilating types:

These are constructed similar to the progressive kilns, except that they are shorter. The heating coils extend the full length, and the air outlets in the side walls are all at the same level—about halfway between the operating floor and the ceiling. Both kinds of kilns have regulating dampers in the vents on the roof.

EMERSON DRY KILN CO., 30 Church Street, New York, N. Y.

Progressive kiln.—

Ventilating type:

The heating coils are located under the tracks and extend the full length of the kiln except at the loading end where there are no coils in the space provided for the steaming chamber. Steam enters the coils at the dry end, making this the hottest part of the kiln. Fresh air enters through two perforated ducts at the bottom of the kiln near the outside rail posts.

It leaves through vents in the side walls near the ceiling. These vents extend downward within the walls halfway to the floor and then out, or, in walls between kilns, they first extend downward and then upward to ventilators on the roof. The outlets are said to be provided with "automatic, gravity, swinging, moisture-regulating dampers." This progressive kiln differs from others previously described, except the Morton kiln, in having air outlets at intervals along the length of the kiln, instead of only at the green end.

Compartment kiln.—

Ventilating type:

This kiln is constructed similar to the progressive kiln, except that it is shorter and is designed for even distribution of heat.

WELCH DRY KILN CO., INC., New Orleans, La.

Progressive kilns.—

The heating coils, which are of the return-bend header type, are located under the tracks almost the complete length of the kiln. A longitudinal duct under the coils admits fresh air and air recirculated from the green end to the dry end where it is heated before passing upward into the lumber. By adjusting the vents, the amount of air to be recirculated can be regulated. Steam jets, located in the duct, may be used to add to the humidity and to increase the rate of circulation.

Compartment kilns.—

Specially designed compartment kilns are also made by this company.

NORTH COAST DRY KILN CO., Seattle, Wash.:

Progressive kilns.—

Ventilating type:

The heating coils are under the tracks and extend from the dry end to within a short distance of the green end. The fresh air is taken in at the dry end through flat perforated flues running along the floor for about one-fourth of the length of the kiln. The air leaves through vertical flues in the walls at the green end, the openings to the flues being midway between the level of the rails and the ceiling.

Non-ventilating type:

Similar to the above but without fresh-air flues.

Compartment kilns.—

Ventilating type:

The heating coils are arranged in horizontal rows under the tracks. The fresh air enters the kiln chamber near the ceiling, coming up within the side walls. It leaves through openings in the side walls at two different elevations above the tracks. These openings connect with vertical flues in the side walls, the walls and flues extending above the roof. The manufacturers recommend the use of fresh-air inlets only at the end of the drying process, much of the circulation in both progressive and compartment kilns being internal and accelerated by means of small-caliber, high-velocity steam nozzles.

An internal-fan kiln made by the Western Blower Co., Seattle, Wash., is also sold by this company.

Superheated-steam type:

Kilns designed for drying by superheated steam are equipped with ample heating coils which together with the steam escaping directly into the kiln chamber raise the temperature to above 212°F. Small-caliber, high-velocity steam nozzles are located in rows in different parts of the kiln according to the design to promote rapid circulation. Sets of nozzles pointing in opposite directions are used alternately, so as to reverse the circulation.

Condensing type:

The North Coast Dry Kiln Co. also builds water-spray kilns when so ordered.

B. F. STURTEVANT CO., Hyde Park, Boston, Mass.

Progressive kilns.—

Ventilating types:

Cross-piling.—This type of kiln is recommended only for air-dried hardwoods when already existing plant conditions make its use desirable. The air, after being conditioned, is introduced at the dry end of the kiln and is withdrawn at the opposite end by a blower. As in other types of this company's kilns the vents leading outdoors are designed to pass only a small fraction of the total amount of air, most of which is recirculated and reconditioned each time it passes through the fan and heating equipment.

End Piling.—This type of kiln operates in practically the same manner as the compartment kiln described below, except that provision is made for bringing up into the lumber varying amounts of air throughout the length of the kiln, subjecting the lumber to varying drying conditions as it progresses through the kiln.

Condensing type:

This kiln is no longer marketed. A fan is used to produce circulation, and a cold-water coil to condense the moisture. The fan, condenser, and heating pipes are located in an adjoining building, the returning air striking them in the order named. The air enters the kiln through openings in the floor at the dry end and is drawn out through openings in the floor at the green end, from where it passes through a duct back to the blower. The green end may be partitioned off with a curtain so as to make a steaming chamber.

Compartment kilns.—

Ventilating type:

The circulation is produced by a fan which, together with the heating coils, is located at one end of the kiln either on grade or underneath the transfer pit. The air is passed through a series of ducts and is admitted into the lumber pile up through an A-shaped flue in the center. From there the air travels more or less horizontally to the sides of the pile of lumber and is drawn into the return duct system which draws the air back to the heating system and thus recirculates the greater part of it. Provision is made for deflecting the air uniformly through the lumber.

The humidity is increased by admitting a flow of live steam, or decreased by expelling a small portion of the air through vents and admitting a corresponding amount of fresh air.

MOORE DRY KILN CO., Jacksonville, Fla.

Progressive kiln.—

Ventilating type:

The heating coils are arranged to produce a graduated heating effect as the lumber is moved forward through the kiln. Extra pipe at the dry end of the kiln provides for a higher temperature at that end and, consequently, a lower humidity. Excess moisture is vented out through openings distributed along the roof. No fresh air is admitted; the lumber is dried at relatively high humidities. Steam sprays provide for extra humidity at the green end when it is needed.

Compartment kiln.—

Ventilating type:

Return-bend heating coils with headers are located beneath the lumber trucks and extend back and forth three times. This arrangement tends to equalize the temperature throughout the kiln. Full-sized pipes extend from the feed header to the drain header, and a fall of 1 inch every 6 feet is provided to clear the pipes of condensation. Any excess moisture escapes through vents distributed along the roof. Fresh air is rarely admitted but may be if desired. Downwardly directed spray lines on the walls and upwardly directed spray lines under the tracks make it possible to heat the lumber rapidly at the start, and also to supply the humidity needed during the run.

This company also builds an internal-fan kiln, as described on page 99.

GRAND RAPIDS VENEER WORKS, Grand Rapids, Mich.

Progressive kilns.—

This company builds progressive kilns in which the air ducts are located similar to those in the compartment kilns described below.

Compartment kilns.—

Ventilating type:

The heating pipes are located underneath the tracks. The air enters the kiln chamber near the ceiling from vertical flues in one of the side walls. These vertical flues connect with a horizontal duct at the bottom of the kiln along the wall, which usually draws the fresh air from the pit in which the steam feed pipes are located. The air leaves through the openings in the ducts at the bottom of the kiln under the heating coils. These ducts connect with vertical flues in the wall opposite the one in which the incoming air flues are located. To increase the draught, a steam pipe is placed in each of the outgoing air shafts. Sliding dampers are fitted over the outgoing air ducts at the bottom of the kiln to regulate the circulation (see Fig. 33).

Combination ventilating and condensing type:

The Grand Rapids Veneer Works builds its ventilating kiln equipped with the water-spray system, if so desired, so that it can be operated either as a ventilating kiln or as a recirculating condensing kiln.

ELMER E. PERKINS CO., Wrigley Building, Chicago, Ill.

Compartment kiln.—**Condensing type:**

The heating coils are located at the bottom of the kiln. The condensing coils are near the ceiling on one or both sides of the kiln.

Ventilating type:

The heating coils in this type of kiln also are distributed underneath the lumber at the bottom of the kiln. The air passes through a horizontal pipe at the bottom of the kiln at one side and is admitted into the kiln chamber through short vertical pipes connecting with the horizontal pipe. It leaves through outlet pipes separate from the kiln walls and at varying elevations at the opposite side of the kiln.

CUTLER DESK CO., Buffalo, N. Y.

Compartment kiln.—**Condensing type:**

The radiators or heating pipes are located near the center line of the kiln under the operating floor or tracks. The circulation is more or less horizontal within the lumber piles and down along the sides where it passes into the suction ducts and is recirculated through the radiators by a blower. The blower is omitted where remodeling of old kilns makes its installation impracticable. The moisture is removed by transpiration through one-thickness canvas curtains on both sides of the kiln. The air circulating upward by gravity between the canvas and outside walls and out at the top through stacks takes the excess moisture from the canvas. The humidity is regulated by regulating the ventilation back of the curtains. The lumber may be steamed by pipes opening into the suction ducts. This kiln is illustrated in Fig. 35.

Ventilating type:

The kiln described above is also built without the curtain condensers; a kiln for cross-piling has been designed by the company without either blowers or condensers.

Another modification, designed for edge-stacked lumber, has the heating units on the walls on both sides. The air rises along the walls and descends through the piles to a duct at the bottom, from which part of it is recirculated by a blower. Part of the air may be vented outdoors through chimneys opening into the kiln on a level with the bottom of the lumber piles.

CURTIS-HOSEY DRYER CO., Bush Terminal, Brooklyn, N. Y.

Compartment kiln.—**Ventilating type:**

The heating coils are located under the operating floor. The air enters through longitudinal ducts under the floor; after passing up through

the lumber piles and down on the sides, it leaves through flues connecting with stacks near the floor level, or it may be recirculated by manipulating dampers so that it again passes under the heating coils instead of outdoors. Steam-jet inspirators are provided in the intake ducts to promote circulation of the air.

Progressive kiln.—

Ventilating type:

The construction of this type of kiln is similar to that of the compartment kiln as far as the ventilation is concerned; that is, fresh-air inlets and outlets for moist air are located at intervals along the full length of the kiln. The temperature of the dry end is kept higher than that of the green end by additional heating coils.

A. S. NICHOLS CO., New York, N. Y.

Compartment kilns.—

Ventilating type:

The heating pipes are located in horizontal layers between the lumber. They are connected on the sides by flexible joints. By means of a hydraulic lift the framework in which the pipes and lumber rest can be raised and opened up somewhat like a bellows and the dry lumber removed and fresh lumber inserted. The air enters through ducts in the front wall and leaves through a ventilator in the ceiling.

NORTHWEST BLOWER KILN CO., Seattle, Wash.

Compartment kiln.—

Ventilating type:

Banked heating coils are housed outside or inside of the kiln chamber. Outside fans blow air into the kiln and exhaust air from the kiln. In flat piling, air enters the kiln and is uniformly discharged through a perforated duct located along the center of the kiln, full length, below the tracks; it is withdrawn through ducts with graduated openings along the side walls. For vertical piling the circulation is in the reverse direction. All the air is recirculated except a small amount which is exhausted with the surplus vapor through dampered vents.

HENDERSON DRYING EQUIPMENT CORP., Syracuse, N. Y.

Compartment kiln.—

Ventilating type:

The fresh air enters through ducts at the bottom of the kiln. A steam-jet injector is placed in the opening of each intake duct to supply the necessary humidity and to promote circulation. The heating pipes, through which the air next passes, are located in banks under the operating floor. Vertical flues with openings at the level of the floor are located in the side walls. Part of the air is expelled through these flues and part recirculated. The intake ducts are provided with control dampers, so that the amount of incoming air may be controlled.

WATER-SPRAY HUMIDITY-REGULATED DRY KILN.

Compartment kiln.—

Condensing type:

The heating coils are under the lumber. The air rises through the lumber, goes to the side walls, and passes downward through cooler water sprays which increase the circulation and also regulate the humidity of the recirculating air (see Fig. 34). In wide kilns the sprays are sometimes placed in the middle and the heating coils on the two sides of the spray chamber. Condenser coils are also provided for use at the end of the drying when a low humidity is desired.

Since this kiln is patented by H. D. Tiemann of the U. S. Forest Service, and the patents dedicated to the public, it may be built by anyone.

REVERSIBLE-CIRCULATION INTERNAL-FAN KILN.

Compartment kiln.—

Ventilating type:

Forced circulation is produced by a series of disc fans mounted upon a shaft running the full length of the kiln, and usually located midway near the bottom of the kiln. Each fan is suitably housed to guide the air in the desired direction, and provided with plenum chambers or other means of producing uniform air flow. Reversing the direction of rotation of the fans reverses the direction of the air travel. Cross-circulation (the plane of the air travel is parallel to the ends of the kiln) is employed for all forms of stacking except the cross-piled, flat-stacked form, in which the circulation is longitudinal in each of a series of longitudinal divisions of the kiln, working independently of each other.

Heating coils are usually located in two groups at the sides of the shaft, in the air stream from the fans, and split up into a number of small units, so that any desired number of pipes may be used.

Air-inlet and air-outlet flues are provided so that the humidity may be reduced through ventilation when necessary. Kilns using this principle of design are built by the Moore Dry Kiln Co. and the North Coast Dry Kiln Co. This kiln was developed at the Forest Products Laboratory under the supervision of Rolf Thelen. A number of patents have been issued and dedicated to the public.

In addition to the above the following firms also manufacture dry kilns:

J. M. Bower, Inc., 236 N. Clark St., Chicago, Ill.	The General Dry Kiln Co., Inc., 613 Maritime Bldg., New Orleans, La.
Brecher & Bernitz, Inc., 25 Beaver St., New York City.	904 Securities Bldg., Seattle, Wash.
Hope Fan and Blower Co., Kansas City, Mo.	1405 American Bank Bldg., Portland, Oregon.
Imrie Dry Kiln Co., 8418 Dexter Blvd., Detroit, Mich.	Sidman Co., Rochester, New York.
	Universal Vacuum Dryer Co., Kansas City, Mo.

CHAPTER VI

THE HEAT IN A DRY KILN

50. Why Heat Is Necessary.—There are many types and makes of kilns, but they are all based on the principle that high temperatures are required to hasten the drying process. In fact, it is principally in the use of higher temperatures that kiln drying differs fundamentally from air seasoning. Heat serves a number of purposes in a dry kiln, and it is necessary to consider these in some detail in order to understand more fully the principles involved in kiln drying lumber.

1. Heat is necessary to evaporate the moisture as it comes to the surface of the lumber. Evaporation always consumes heat. Therefore, the supply of heat must be kept up or the surroundings will become cooled so that evaporation will be greatly reduced, or will cease altogether. The principle that evaporation produces cooling is exemplified in a number of ways. A cloth-covered canteen after being dipped into water will keep the contents cool for a long time because of the cooling effect of the evaporation from the surface. The wet-and-dry-bulb hygrometer, which will be explained in Chap. VII, also works on this principle.

The heat required for evaporation is entirely consumed for the time being. The vapor or steam produced is no warmer than the liquid from which it comes, although it takes a large amount of heat to convert the liquid into a vapor. The heat used up in this way is known as the *latent heat of vaporization*.

The amount of heat required to evaporate a pound of water without raising its temperature is approximately 1,000 British thermal units¹ at ordinary temperatures and becomes less at higher temperatures.

Neither a vacuum nor increased circulation will decrease the amount of heat required. The only advantage of a vacuum is that it causes evaporation to take place more rapidly than it

¹ A British thermal unit (B.t.u.) is the amount of heat required to raise the temperature of 1 pound of water 1°F.

would otherwise at any given temperature. Hence, rapid evaporation can be secured where low temperatures are necessary, as in condensing milk. The vacuum principle is not applicable to lumber kilns since it is not so much increased evaporation that is needed as more rapid transfusion of the moisture from the interior to the surface of the lumber.

The latent heat of vaporization can be recovered by condensing the vapor back into the liquid form. This may be accomplished by bringing the vapor into contact with a body cooler than the vapor. In fact, this is what takes place in all steam-heating systems. The steam condenses in the radiators and thereby loses its latent heat, returning to the boiler as condensation which is only slightly cooler than the steam which entered the radiator. This action also accounts for the rapidity with which the condensing water heats in condensing kilns.

In a dry kiln, therefore, in which large quantities of moisture are evaporated, much more heat is required than that which is necessary to replenish losses due to radiation. A truck load of green lumber may readily contain 2 tons of moisture to be evaporated, which would mean the expenditure of about 4,000,000 B.t.u. without allowing for any other heat losses. The total amount of heat required to dry the lumber would probably be from two to ten times that amount.

2. High temperatures hasten the transfusion of moisture from the interior to the surface. Hot water will pass through wood more easily than cold water, whether it is going out or in, probably chiefly because of the decrease in the viscosity of water with increase in temperature, although this is counteracted to some extent by the decrease in capillary action, as is indicated by the graphs in Fig. 39. The increased vapor pressure within the wood at the higher temperatures also increases the rate of diffusion of the water vapor outwardly along the cell cavities. Since the rate of drying depends upon the speed at which the moisture can come to the surface to be evaporated, the higher the temperature the more rapidly the lumber will dry, provided excessive surface drying does not seriously interfere with the transfusion of moisture. In fact, this is the chief reason for maintaining high temperatures in a kiln. Plenty of surface evaporation may be obtained at lower temperatures if a low humidity and a good circulation of air are maintained. If the drying of lumber were only a matter of evaporating the moisture

from the wood, most of the present troubles in kiln drying would not exist, but the transfusion of moisture is a slow process and, therefore, causes numerous complications. It can be hastened only by increased temperature and by maintaining a certain difference in the moisture contents of the outer and inner portions of the wood.

The claim is sometimes made for certain methods of drying that the wood dries from the inside out; that is, the interior becomes dry first. This is supposed to be accomplished by

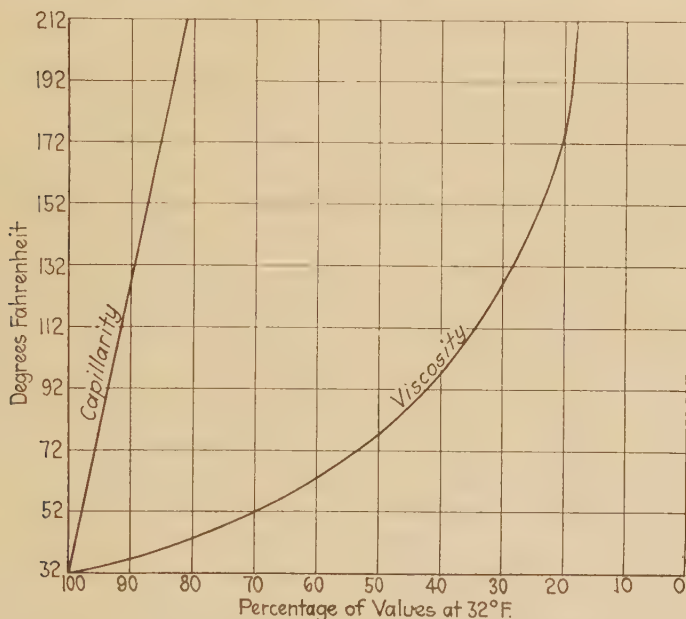


FIG. 39.—Curve showing effect of temperature on capillarity and viscosity of water. (*Smithsonian Physical Tables.*)

In general, the viscosity of solutions of organic and inorganic materials in water is somewhat greater than that of pure water. The capillarity (surface tension) of solutions of many inorganic salts in water is slightly greater than that of pure water, and of many organic liquids it is considerably less.

heating the lumber through to the interior; the high temperature is then supposed to drive the moisture out.

A little reflection will show that the interior of any substance cannot become dry before the exterior is at least equally dry. If high temperature in itself did “drive” moisture, it would first drive it toward the center of the lumber as it is being heated; and later, when the interior became as hot as the surface, the moisture would go neither in one direction nor in the other.

Moisture travels from the inside to the surface layers only because the surface layers are drier, the moisture having a natural tendency to pass from the wetter to the drier portion. Therefore, while lumber is drying, the outer shell must always have a somewhat lower moisture content than the core.

3. Heat is required to separate water from wood below the fiber-saturation point, the amount of heat per pound of water evaporated increasing as the wood becomes drier. This, however, is a small amount compared with other heat requirements

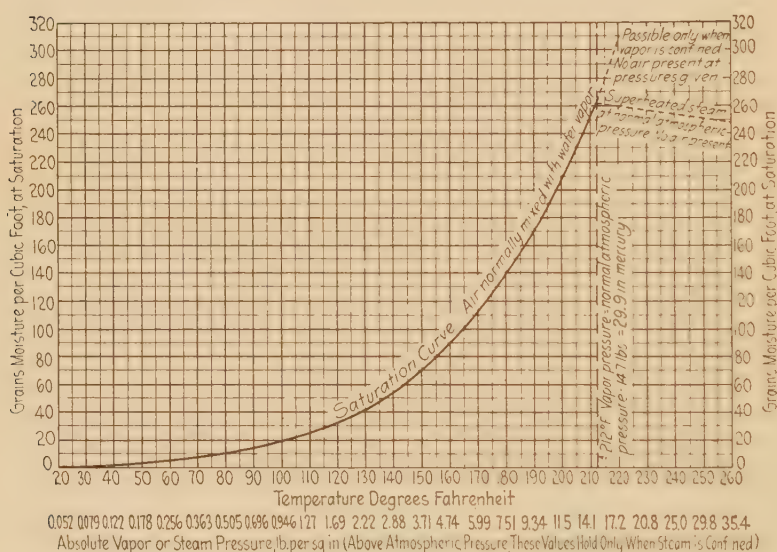


FIG. 40.—Grains of moisture per cubic foot at various temperatures when saturated and when superheated at normal atmospheric pressures.

—about 34 B.t.u. per pound of wood (dry weight) dried from saturation to complete dryness.

4. Increasing the temperature increases the capacity of the air for moisture. In fact, the moisture-holding capacity of air, when it is heated, increases more rapidly than the temperature increases, so that adding a few more degrees of heat to the air greatly increases its capacity for moisture. Hence, it is more economical to dry lumber at high temperatures because the air need not be changed so often for every 100 pounds of water evaporated. The following figures show how greatly the mois-

ture-holding capacity increases with increase in temperature. It almost doubles for every 20°F. This relation is shown graphically in Fig. 40.

DEGREES FAHRENHEIT	NUMBER OF GRAINS OF MOISTURE PER CUBIC FOOT OF AIR WHEN SATURATED
20.....	1.24
40.....	2.86
60.....	5.8
80.....	11.1
100.....	20
120.....	34
140.....	57
160.....	91
180.....	140
200.....	208
220.....	302 (17.2 pounds absolute pressure)

The increased capacity at the higher temperatures is offset to a large extent in a kiln by the fact that higher relative humidities must be maintained at higher temperatures in any given stage of drying. This subject will be discussed more fully in Chap. VII.

The same principle is involved where superheated steam is used for drying instead of air. The more the steam is superheated, the greater is its capacity for moisture.

5. Heat produces circulation. In all kilns not equipped with mechanical means of producing circulation the change of air is brought about by the hot air rising and the cooler air falling. No natural circulation can take place in a kiln in which the temperature throughout the interior is uniform.

6. High temperatures, such as are usually maintained in a kiln, prevent decay, blue stain, and mold during kiln drying. All of these are due to fungous growths, but of different kinds, which thrive on damp wood when warm but are killed when the surroundings become too hot. Decay does not make any appreciable progress at temperatures over 105°F. and is entirely arrested at approximately 115°F.,¹ although it takes a somewhat higher degree of heat to kill certain wood-decaying fungi. Temperatures such as are usually maintained in a dry kiln toward the end of the drying process sterilize the wood so that it must be infected anew before it will decay.

¹ This refers to the temperature of the wood, which, when wet, corresponds more nearly to the temperature indicated by the wet bulb of a hygrometer.

Recent experiments have shown that it is possible to sterilize wood in a dry kiln during comparatively short steaming periods. For example, certain wood-destroying fungi were killed in steaming stock 4 inches thick at a temperature of 120°F. and 100 per cent humidity for twenty-four hours, or at a temperature of 145°F. and the same humidity for three hours. If wood so sterilized is stored in well-ventilated piles protected from moisture, except the moisture absorbed from the air, there is every reason to believe that the stock will remain bright and sound while in storage.¹

Lumber left in kilns for a long time at temperatures less than 85°F. and at high humidities is in danger of becoming brash on account of decay setting in, especially in the sapwood. If decay-infected lumber is insufficiently dried at low temperatures, it may not become sterilized, and decay may continue after the lumber is taken from the kiln, producing what is known as "interior dote."

Conditions similar to those which apply to decay also apply to blue stain, except that the blue-stain fungi are more rapid in their action, and according to recent tests appear to require higher temperatures for sterilization.

Molds (these grow principally on the surface layers) are not so sensitive to high temperatures. Certain kinds of molds grow rapidly on moist wood at 110 and 115°F. if the humidity is high; consequently, mold causes a great deal of trouble in drying green stock for which such conditions must be maintained. The mold does not harm the lumber in itself, but it interferes greatly with the circulation in the kiln. It acts like the hair on a dog's back in that it keeps the currents of air off the surface. It takes a temperature of about 135°F. to prevent entirely the growth of mold and about 170°F. to kill it. The best way to prevent mold growth is to steam the lumber at 170°F. for from half an hour to two hours, the length of time depending upon how good the circulation is in the kiln. Care must be taken to have the air saturated or nearly so, otherwise the lumber will check. After the lumber is steamed, the drying should be resumed gradually. Even this temperature will not kill the spores (tiny seeds),

¹ HUBERT, E. E., "The Effect of Kiln Drying, Steaming, and Air Seasoning on Certain Fungi in Wood," United States Department of Agriculture Bull. 1262, 1924.

HUBERT, E. E., "The Heat Treatment of Infected Wood," *Hardwood Record*, Oct. 10 and 25, 1924.

which may later germinate, making it necessary to steam the lumber again in a week or two if the humidity is high enough to make possible the growth of another crop.

7. Temperatures above 130°F. maintained for an hour and a half, or longer, are fatal to powder-post beetles;¹ very likely ordinary kiln-drying conditions are fatal to all insects that may be in lumber at the time it is kiln dried.

8. Heat makes wood plastic, reducing its tendency to develop internal stresses as it dries and shrinks and tends to warp or cup. Wood properly dried at high temperatures is more apt to remain straight than wood dried at low temperatures.

Furthermore, heat may change the properties of wood sufficiently to affect its further utilization. High temperatures darken wood all the way through or darken the surface particularly, giving the lumber a scorched appearance known as kiln burn. Wood subjected to high temperatures loses some of its capacity to hold moisture and, therefore, is not affected so much by changes in atmospheric humidity.

Wood kept in a kiln at temperatures somewhat above 150°F. for any length of time is not so strong as that dried at lower temperatures, the weakening varying with the temperature and the length of time it is maintained.

51. How the Heat Is Supplied to the Lumber.—There are only three ways by which heat can be supplied to any object, and only one of these—convection—is practical in a dry kiln:

1. By conduction, that is, by direct contact with the source of heat. This method is used in veneer driers, in which the sheets are put between hot plates which come in direct contact with the wood. Lumber cannot be dried by this method because it would caseharden severely and because the capacity of such apparatus is too small.

2. By radiation, that is, by the direct passage of heat rays from the source of heat. This method of heating, of course, also is impracticable in drying large quantities of lumber. However, the boards in the bottom layer of lumber piled in a kiln, with heating coils underneath the trucks, may receive heat by radia-

¹ SNYDER, T. E. and ST. GEORGE, R. A., "Determination of Temperatures Fatal to Powder-post Beetle, *Lyctus planicollis* Le Conte, by Steaming Infested Ash and Oak Lumber in a Kiln," U. S. Department of Agriculture *Journal of Agricultural Research*, vol. XXXVIII, no. 10, June 7, 1924.

tion, but should be protected against it, or they will become much hotter than the others and may become injured. The thermometers and the hygrometers must also be shielded against direct radiation from the heating pipes or they will not show the true condition of the surrounding air.

3. By convection, that is, by currents of heated air or vapor. This is the only practical means of getting the heat to the inside of a lumber pile.

52. Methods of Supplying Heated Air.—Hot air may be supplied to the kiln through a number of different media and by widely varying methods. Many methods have been used from time to time, and although many of them are obsolete or impracticable, mention will be made of them for the sake of completeness.

(a) *Direct Furnace Heat.*—In this method of heating, smoke and other products of combustion are led direct from an open fire or ordinary furnace into the kiln, from which they are exhausted through a chimney or other suitable means. As stated in Chap. V, kilns of this type are known as “smoke kilns.” At one time it was thought that lumber dried in smoke kilns was superior to steam-dried stock. Now, however, their use has been largely abandoned. Figure 27 shows a smoke kiln in use at the present time. A cruder “kiln” can hardly be conceived of.

(b) *Indirect Furnace Heat.*—Occasionally, when it is desired to avoid the use of steam under pressure, and the smoke kiln is too crude for the purpose desired, hot-air furnaces are used. The furnace may be located at the side of the kiln, or under it. The distributing ducts are arranged to carry the heated air from the top of the furnace into the kiln so as to distribute it uniformly. Return ducts leading to the bottom of the furnace may also be provided. The products of combustion do not enter the kiln but pass directly up a smokestack.

(c) *Gas.*—Natural or artificial gas is sometimes used to heat small dry kilns, the burners being arranged much as in an ordinary household gas oven.

(d) *Electricity.*—Electric heat may be used in small kilns, although the cost of current is prohibitive except for experimental units.

(e) *Hot Water.*—Hot water heat may readily be adapted to the heating of kilns which do not demand too high a temperature.

However, a suitable supply of hot water would rarely be available in the absence of steam, and the cost of the installation would be appreciably greater than for steam.

(f) *Steam*.—At present, steam is almost universally used for heating dry kilns of all types, so that a knowledge of its use is essential to intelligent kiln operation.

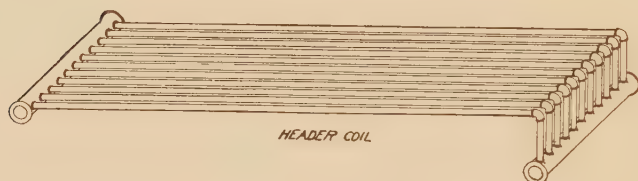
Steam is usually delivered to the kilns through a pipe main or mains from the boiler house or power plant and may be either "high-pressure" steam (above 10 pounds per square inch pressure) or "low-pressure" steam (below 10 pounds). High-pressure steam is almost invariably live steam, for example, steam direct from the boilers; while low-pressure steam is frequently exhaust steam, or steam which has passed through the engine, pump, or turbine on its way from the boilers to the kilns, accomplishing useful work in doing so. High-pressure steam is, as a rule, much drier than low-pressure steam, principally because the latter generally carries with it much water condensed in its passage through the engine or other unit in which work has been done by the steam.

53. Steam-heating Apparatus.—Kilns usually are supplied with steam radiators of one kind or another. The heat imparted to the radiators by the condensation of the steam is transferred to the lumber by the air and vapor which pass over the radiators and then through the lumber piles.

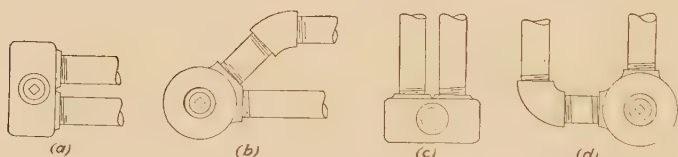
The form, construction, and arrangement of the radiators are of importance. There are several common types of radiators; several others are not so common, but are efficient nevertheless. Of all the various types, those constructed of pipe coils are in most common use. Among the advantages of this type may be mentioned low first cost, ease of manufacture and installation, ready adaptability to a tremendous range of shapes and sizes, ease of repair by the shop mechanic or millwright, and a high heat-transmitting efficiency. A good pipe coil must have certain qualifications: First, it must be of such size and shape and so located that it can heat the air in the kiln in the proper manner; second, it must be mechanically strong and durable and provided with means for permitting the expansion and the contraction of the individual pipes in the coil; third, it must provide for the ready escape of air and water of condensation from the entire system; fourth, it is essential in many cases that the amount of heating surface be readily adjustable by changing the number of



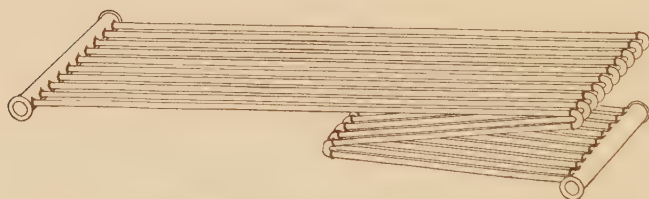
RETURN-BEND COIL



HEADER COIL



HEADERS FOR DOUBLE-ROW HEADER COILS



HORIZONTAL RETURN-BEND HEADER COIL



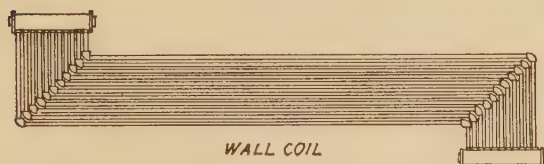
VERTICAL RETURN-BEND HEADER COIL

FIG. 41.—Pipe coils for heating dry kilns.

Many kinds of pipe coils are used in dry kilns. Of those illustrated, the single-row and double-row header coils and the return-bend header coils are in the most common use. The return-bend coil is used in short kilns which require uniformity of temperature. The vertical return-bend header coil may be made with a short length of pipe and two elbows replacing each return bend. The drain header must be somewhat lower than the supply header to secure proper drainage.



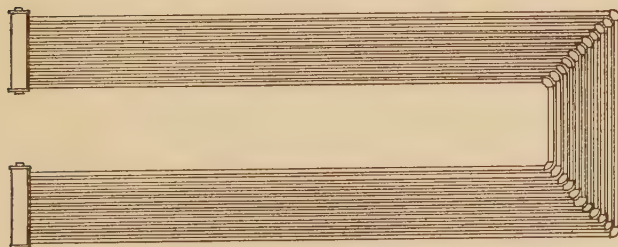
SINGLE HEADER COIL



WALL COIL



3-HEADER FLAT COIL



DOUBLE HEADER FLAT COIL

FIG. 41.— (Continued.)

The single header coil is unique in that the condensation must drain back through each pipe, opposing the flow of steam. The free end must be raised sufficiently above the header end to provide good drainage.

The last three coils illustrated are all flat and can be used either vertically or horizontally. When they are used vertically, the bottom header in each case is the drain header. When they are used horizontally, the 3-header flat coil may drain through any one or any two of the headers, depending upon how the coil is pitched.

pipes in use. It is practically impossible to combine all of these essentials in the highest degree in any one type of coil, so that various types are in use, different ones having been found best adaptable to various specific uses.

A large proportion of all the pipe coils used for dry-kiln heating is located in the kiln proper, usually between or under the rails. These coils fall, loosely, into two general classes, known respectively as "header" and "return-bend" coils. In the former, a number of pipes spring from the same supply pipe or header, technically known as a "branch tee," and return to a similar drip pipe or header, which is usually located at the other end of the kiln. In the return-bend type, however, the pipes of each group are connected end to end by return bends or double-elbow fittings; the steam enters at the front of the first or top pipe, flowing in turn through all the other pipes, and the condensation is removed from the end of the last or bottom pipe. Figure 41 illustrates various types of header and return-bend coils. The construction of the various kinds of coils will become evident upon inspection of the figure.

54. Header Coils.—The header coil is sometimes known as a "harp coil." If the runs (the long pipes) and the springers (the short ones) are horizontal and the headers are vertical, the coil is a "corner coil." This type is often used in factory heating, where it is convenient or desirable to have the heating surface extend along two walls from a corner. The springers may be of the same size of pipe as the runs, or they may be considerably smaller, sometimes one-half inch, or even three-eighths inch nominal diameter. The use of the smaller pipes reduces the excess of radiation at the discharge end and increases the flexibility of the springer. Cast-iron reducing elbows should be used with springers of small diameter. For corner coils they should be of a special eccentric reducing type to permit free drainage unless the springers are at the inlet end. The elbows are tapped right-hand and the drain header left-hand, the springers being, of course, threaded right and left.

Header coils are sometimes made with two rows of pipes and only one pair of headers. Each header is tapped with two rows of openings—one row above the other. In one form of construction the supply header is tapped with two rows as shown in Fig. 41b, one row being horizontal the other row pointing upward and to the right at 45 degrees. Short pieces of pipe—about 6 inches

long—are screwed into this row, and a 45-degree elbow screwed on the upper end of each pipe and pointed horizontally. The upper run of pipes is then screwed into these elbows, the springers for this row entering the drain header from the top, as illustrated in Fig. 41*d*. The springers for the lower row of pipes enter the drain header from the left side, an extra elbow and nipple being used on each pipe. This construction is compact, but it has little else to recommend it.

55. Wall Coils.—The wall coil is a flat header coil and, therefore, usable in places—particularly on walls—where there is no room for other forms of header coil. The form illustrated in Fig. 41 provides the same amount of springer length for each pipe and gives a uniform longitudinal distribution of heating surface, except for the headers themselves. One set of springers is threaded right and left to permit assembly of the coil. Wall coils used in factory heating are usually of the “L” type, with only one set of elbows and one of the headers vertical. The form of coil illustrated could be made into two “L” coils by cutting it vertically in two through the center and fitting two vertical headers onto the cut ends. Wall coils may be used horizontally if desired; sometimes it becomes convenient to use two side by side. They can then be made into a single “double” coil by using a single drain header for both, tapped with two rows of openings opposite each other. Wall coils may also be made with two banks of pipe a few inches apart, the headers being tapped with the two rows of openings parallel to each other.

56. Return-bend Coils.—The return-bend coil, sometimes known as a “trombone coil,” is usually made up with standard cast-iron 180-degree return elbows, threaded right hand, which can be secured in various standard patterns differing from each other only in the distance between the tapped openings. In assembling, the pipes can be sprung sufficiently to permit the elbows to be turned. If the steam inlet and the drain connections are to be on the same end of the kiln, the coils should be made up with an even number of pipes; but if they are to be on opposite ends, they should be made with an odd number. This will bring the ends of the coil into the correct position. When repairs are needed, the simplest scheme is often to break one of the elbows, remove a length of pipe, and replace it with a new length, threaded right and left, and a right and left return elbow; or to use a right and left coupling and a two-piece run of pipe.

57. Return-bend Header Coils.—The vertical return-bend header coil can be assembled as shown in Fig. 41, or with two elbows and a short pipe to replace the return elbow. This arrangement separates the two banks of pipe any desired distance, depending upon the length of the pipe between the elbows. The form illustrated can be made up with right and left return elbows or with one left-hand header. The other type can best be assembled if the short pipes are threaded right and left, using one set of right and left elbows. Both headers are at the same end, the drain header being lower than the supply header to afford drainage. Larger coils can be made with three or more runs instead of two. The drain header will be located at the other end from the supply header if an odd number of runs is used.

The construction of the return-bend header coil with horizontal headers needs no further explanation. This type of coil can be used to advantage when there is ample space vertically. The heat distribution can be varied by varying the length of the return pipes.

58. Miscellaneous Types of Coils.—There are many other forms of pipe coils which are occasionally used for dry-kiln work where some unusual conditions make it desirable to depart from accepted practice. In fact, an infinite variety of designs is possible. One interesting form used in a high-temperature kiln for drying softwoods has only one header, which serves for both supply and drain. This header has one very broad face which is tapped for three or more parallel rows of pipe. Each pipe springing from the header runs the full length of the kiln and is capped at the far end. The entire bank of pipes is tipped slightly so that the capped end is higher, facilitating the drainage of the water of condensation back to the header, from which it is drained in the usual manner. This type of coil is very easily assembled and repaired, but trouble is apt to be experienced from interference between the steam flowing from the header and the water flowing toward it in the same pipe, particularly in long kilns. This may be avoided by using comparatively large pipes, but these are more expensive per unit of heating surface than the sizes usually used.

59. Action of Various Types of Coils.—The action of the various types of coils is markedly different, especially when the

steam flow is intermittent, as when air-operated thermostats are used.

When steam is turned on in a plain-header coil, which has a header at each end of the kiln, the end of the kiln nearer the supply header will heat up first, and the other end will not heat until the supply end has become hot and all the air has been exhausted from the coil. This uneven heating will be repeated each time the thermostat opens; and if the heating surface in use is unduly large, as it may readily be when low temperatures are used, the thermostat will operate often and there will be a marked difference in temperature between the two ends of the kiln. When, however, the steam pressure in the coil is fairly high and reasonably constant, header coils give very satisfactory results. To get away from the effects of uneven heating, it is advisable in many cases to divide the heating system into several units separately valued, so that the amount of heating surface can be adjusted to suit temperature requirements. Another peculiarity of the header system is that the large heating surface of the headers themselves causes an uneven distribution of heat, producing a "hot spot" at each header.

The wall coil behaves similar to the header coil, the supply end becoming hot before the drain end. Coils of this type are used on the walls of superheated-steam kilns.

In the return-bend type of coil, on the other hand, the top pipes in each group become hot first, as the steam enters them first and travels through the others in succession. Obviously, since each pipe runs the full length of the kiln, the heating will be practically uniform from end to end.

The return-bend type also has drawbacks, among which are the first cost and the amount of headroom which the vertical arrangement of the groups of pipe demands. This headroom must be sufficient not only for the pipes themselves and the return bends, but also for a certain amount of downward pitch from the supply end to the discharge end of each group. This pitch causes adjacent pipes to form a "V" with each other, and, therefore, the headroom required for any given number of pipes increases rapidly with the length of the kiln. The resistance to the steam flow also is comparatively great. The return-bend coil is specially adapted to short kilns requiring accurate temperature control.

The return-bend header coils with vertical headers are largely free from the troubles mentioned, particularly if the two headers are at the same end of the kiln and thus balance the uneven heating effect. They are well adapted to short kilns if they can be arranged so that they heat the air efficiently and uniformly, but they require increasing headroom with increasing kiln length.

The return-bend header coil with horizontal headers can be made with all the runs of pipe of the same length; and where the headroom is sufficient to permit its use, it heats uniformly and quickly. As already pointed out, it can also be used to advantage where more heat is needed in one end of the kiln than in the other, by varying the length of the runs.

60. Constructional Details of Pipe Coils.—Pipe coils are usually made of 1- or $1\frac{1}{4}$ -inch black pipe. The 1-inch size is very popular for header coils, the $1\frac{1}{4}$ -inch size being preferred for return-bend coils. There is no hard-and-fast rule, however, for the size of pipe to use, the price and the availability of pipe and fittings being probably the most important factors in determining the choice. It should be mentioned that there is more need for large pipes in return-bend coils than in header coils because all the steam and condensate for any group of pipes must pass through each pipe.

Ordinary merchant pipe is often used for coils. A number of kiln companies use a special pipe of a better grade than merchant pipe, and occasionally they use extra-heavy pipe. Where acid comes from the wood in sufficient quantity to attack seriously steel pipe, wrought-iron pipe should be used. The fittings for the coils are almost always of cast iron. They are excellent in every way and have the advantage that they can be broken with a hammer when it is difficult or impossible to unscrew a joint in making repairs.

The proper proportioning of the parts of the various types of coil to provide ample room for expansion and contraction of the individual pipes with temperature changes requires careful consideration. There is no recognized standard of practice in this regard, since individual designs vary widely. The direct result of insufficient provision for expansion and contraction is leakage at the joints, a fault difficult to remedy without redesigning the coil. Return-bend coils, return-bend header coils, and units with single pipes capped at the ends require no special provision for expansion or contraction since each run is free to

take care of itself. Header coils without return bends, wall coils, corner coils, and similar types must have springers of ample length. Current practice indicates that the springer, if of the same diameter as the run, should be at least 2 per cent of the length of the run, and preferably 3. Thus, for a 100-foot kiln, the springers should be, preferably, 3 feet long. If the springers are of smaller pipe, they may, of course, be shorter. This rule is based on the assumption that the pipe in the runs is 1 or $1\frac{1}{4}$ inches in diameter. Heavier pipe needs proportionally longer springers, as do also very short coils.

✓ **61. Installation of Pipe Coils.**—The installation of the pipe coils must be properly done if satisfactory service is to be expected. Each pipe should be firmly supported at sufficiently frequent intervals to insure its remaining straight and free from leaks and air pockets. Usually a support combined with the rail supports is provided every 6 or 8 feet. For pipes in horizontal banks, all that is needed is a steel bar or structural shape for each layer, bolted or riveted to the track supports. For coils in vertical banks, hook plates are usually used. These come in a variety of styles, most of which have the hooks spaced at standard distances apart. They are excellent for vertical-header coils but cannot be used very well for return-bend coils, since the pitch required for drainage makes the distance between adjacent pipes variable along the length of the kiln, increasing from the return elbow connecting them. For return-bend coils it is usually necessary to make special hook plates out of bar iron and hook bolts, each bar drilled for the individual pipe spacing at that point.

Coils of all types must be mounted so that the coils as a whole can expand and contract with temperature changes in the kiln. An allowance of 1 inch per 100 feet of length is ample. The supply and drain connections must be made with the same thought in mind. It is customary to make this provision by running the pipe lines at right angles to the expected motion for several feet, so that they may act as springers. To prevent creeping, the coils should be anchored firmly to one support, preferably near the inlet end.

The proper drainage of the water of condensation from the coils cannot be secured unless they are pitched toward the drain end. The amount of this pitch may be small if the pipes are well supported, but assurance must be had that it is not

eliminated through settling of the supports or other accidental causes. A pitch of from $\frac{1}{8}$ to $\frac{1}{4}$ inch per foot of run, or from 1 to 2 feet in a hundred, is ample for all conditions. In inclined tracks the coils are often pitched with the track and parallel to it. This method, however, tends to make the green end of the kiln, in progressive kilns, hotter than it should be. A pitch of one-half of 1 per cent may suffice if headroom is limited and plenty of pressure is carried on the coils. With return-bend coils it is often necessary to use a small pitch, since the pipes slope alternately forward and backward, increasing the depth of the coil very rapidly as the kiln length increases.

The exact location of the pipes in the kiln is generally determined by the design of the kiln and the air circulation. The essential requirement is that they shall be in the direct path of the circulation and shall not interfere with it beyond the friction and baffling effect caused by the passage of the air over them.

To secure the best results it is very desirable that the heating surface be broken up into a number of separate units, each independent of the others, so that the proper amount of heating surface for the work in hand may be selected and the steam kept on full almost continuously in the unit or units in use. This will produce the most uniform heat distribution possible. The most convenient way to divide the coils is to make three units, two with two-fifths of the total number of pipes each, and the other with the remaining one-fifth. This gives five possible combinations in even steps of fifths from one-fifth to the full capacity. In almost all kiln designs it will be found that efficient distribution of the heat, when the various combinations are used, requires that each of the three units be divided into two sections, one section on the right side of the kiln and the other in a corresponding position on the left side. These two sections are connected together at both ends and function as a single unit, with single supply and drain connections.

Generally, the principal heating units are under the rails, except in blower kilns which have external heaters, and in those superheated-steam kilns which have the coils on the side walls.

62. Cast-iron Radiators.—Cast-iron radiators of various kinds have recently been introduced for use in dry kilns. They can be secured in a wide range of sizes and shapes adapted to practically any space or heating requirement. This type of radiation is undoubtedly higher in first cost than some other types,

but great durability is claimed for it on account of the well-known resistance of cast iron to rust. The heat-transmission efficiency is also high. Figure 42 shows an installation of cast-iron radiators in a dry kiln.

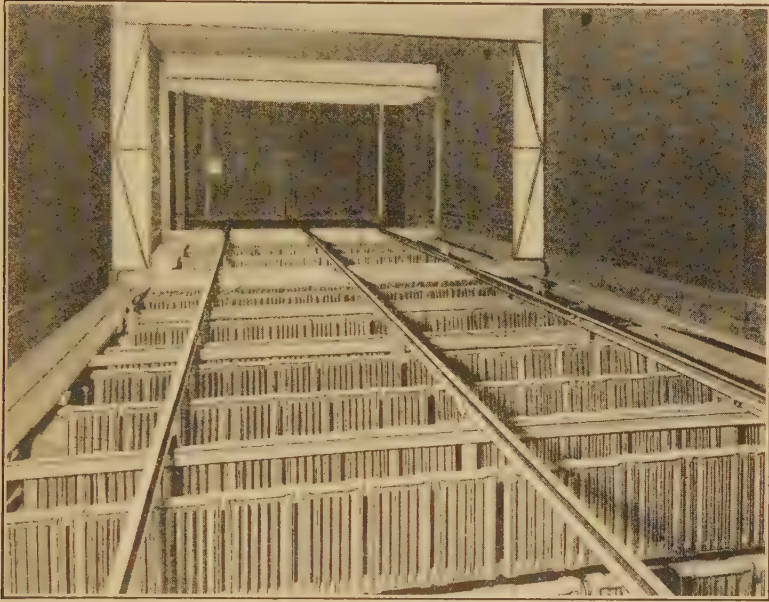


FIG. 42.—A typical installation of cast-iron radiators in a three-rail cross-piled dry kiln. (Courtesy, American Radiator Co.)

63. Unit Heaters.—Various kinds of blower kilns have the heating units located entirely outside the kiln. These units are usually of the standard types used in blower systems for heating buildings. Practically all of these units consist of compactly arranged groups of pipes or pipe coils made up into cast headers which form the base of the heater, although sometimes special forms of cast-iron radiators are used. Heaters of this type give but little trouble from any cause, since their design permits of unusually easy venting of air and water, and the short pipes are free from difficulties caused by uneven expansion and contraction. Figure 43 shows a standard Sturtevant heater unit, with the front of the casing removed, used on one of the experimental kilns of the Forest Products Laboratory. The cast-iron base is

so arranged that the steam enters the right leg of each coil, and the condensation is drained off through special cored passages so that it does not interfere with the entering steam.

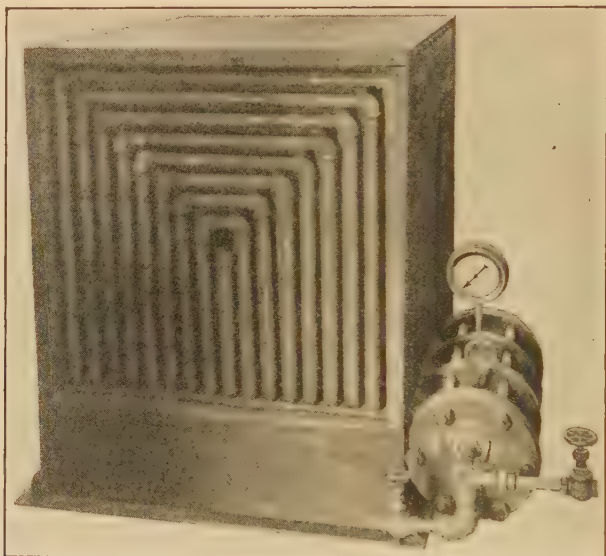


FIG. 43.—Typical heater coils for blower kilns. (Courtesy, Forest Products Laboratory.)

These coils are usually located outside of the kiln proper, and on the suction side of the blower. Steam enters through the upper half of the receiver at the right, and condensate is drawn off from the lower half. The cast-iron base into which the pipes are screwed is cored so that the steam and the condensate have separate paths and do not interfere with each other.

64. Ceiling Coils.—It is often found, especially when kilns are operated at high humidities, that it is desirable to have some pipes at the ceiling to counteract the condenser effect of the roof and prevent condensation and dripping on the lumber. These ceiling coils are usually of pipes spaced $1\frac{1}{2}$ to 2 feet apart and connected in the form of a return-bend coil, with two elbows and a short piece of pipe between each two runs. If the coils are installed this way, they must be level longitudinally and pitched slightly to the side of the kiln to secure drainage. Several other forms, such as header coils, may be used to meet individual needs. Ceiling coils should be entirely independent of the rest of the heating surface and be provided with a separate valve and trap. They are usually left on continuously while the kiln is in operation.

65. Steam-control Apparatus.—Various forms of auxiliary apparatus, such as steam valves, reducing valves, condensation traps, and air-relief valves, are required to permit of the proper manipulation and operation of the heating system. In addition, special instruments for temperature control and regulation are usually installed.

(a) *Steam Valves.*—Steam valves are usually of the standard types commonly used in steam lines. Generally, brass globe valves of high grade will be found satisfactory; gate valves are, however, sometimes used on low-pressure systems because they do not obstruct the flow of the steam and condensation so much. Where the valves are to be used for regulating the steam flow, and not simply to turn it on and off, globe valves should be used in all cases. They are usually installed with the pressure up against the valve discs, that is, the steam flowing upward toward the stem. This permits packing the valve with the pressure on and provides better throttling regulation at the small valve openings. In horizontal runs, the valves are usually installed so that the handle is at the top or on one side. The latter arrangement permits of better drainage of the system and prevents the possibility of the collection of condensation in the pocket under the valve seat.

(b) *Reducing Valves.*—The pressure in the steam main is frequently higher than necessary to furnish the desired temperature in the kiln, so that it becomes desirable to interpose a reducing valve between the steam main and the kiln. The pressure may be reduced by this means to almost any desired point. The variations in the reduced pressure are usually much less than those in the high-pressure main. If the pressure reduction necessary is very great, say from 100 pounds per square inch down to 1 or 2 pounds, it may be necessary to install two reducing valves in series, the first one reducing down to, say, 10 pounds and the second making the final reduction. In an installation of this kind, a steam receiver or a couple of lengths of pipe should be placed between the two reducers to provide a cushion and thus prevent the first reducer from chattering. Reducing valves should always be so installed that they can be readily removed for repairs. Whenever a battery of kilns is run part time on exhaust steam and part time on live steam, it is very desirable to have a reducer between the boilers and the steam main to the

kilns so that the live steam may be supplied to this main at about the exhaust pressure.

There are many types of reducing valves on the market, each designed for a specific range of work. Almost all the types are so designed that the steam at reduced pressure, operating through a diaphragm or a piston on the valve stem, tends to close the valve, and an adjustable spring or sliding weight is provided to resist this pressure and to open the valve. The

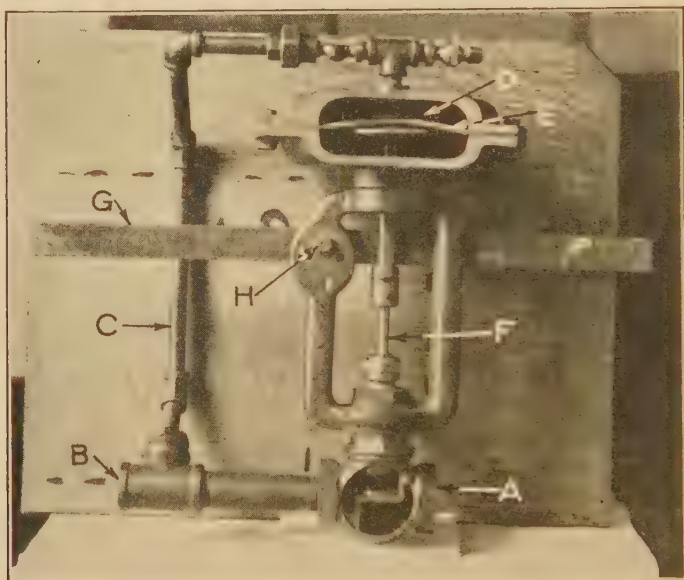


FIG. 44.—A pressure-reducing valve for steam. (Courtesy, Forest Products Laboratory.)

This valve is especially designed for low reduced pressures. Steam enters at *A*, is reduced in pressure as it passes through the valve, and passes out at *B*. The pipe *C* transmits the reduced pressure to the chamber *D*, through the rubber diaphragm *E* to the valve stem *F*, tending to close the valve. This tendency is resisted by weights upon the arm *G*, which is pivoted at *H*. By adjusting these weights, the reduced pressure is regulated.

The chamber *D* is intended to be filled with water, to preserve the diaphragm, and for this reason the valve is usually mounted upside down. The water will then not siphon out when the steam is shut off.

valve opens when the reduced pressure falls, admitting more steam, and closes partially or completely when the reduced pressure rises and reaches a balance with the spring or weight. Thus the reduced pressure is kept constant within close limits. Some types are especially adapted to service where the flow of steam is continuous, but they do not operate so well if the flow is discontinuous. The double-piston valves used in these types are difficult to keep absolutely tight; and if the amount of steam

used is very small, they will leak and allow the reduced pressure to rise. Other types seat positively and remain tight when shut. Some of these are operated by special pilot valves within the main valve, making its action very positive. Occasionally,

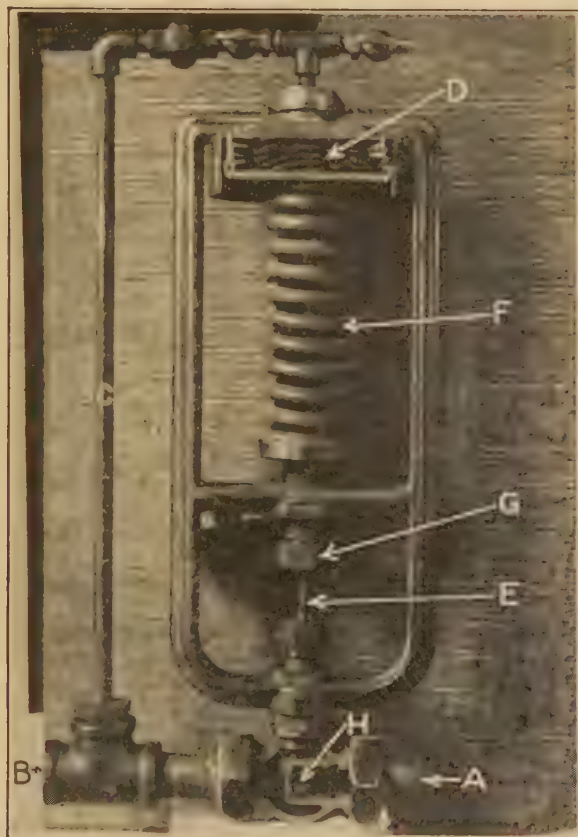


FIG. 45.—A pressure-reducing valve for steam. (Courtesy, Forest Products Laboratory.)

This valve is of the balanced type, spring-operated, with a metal bellows. Steam enters at *A*, passes through the balanced valve *H*, and out at *B*. The reduced pressure is transmitted to the metal bellows *D* through the pipe *C*, and tends to push down the valve stem *E*, closing the valve. The spring *F* resists this tendency, and its adjustment through the adjusting nut *G* controls the amount of the reduced pressure.

the small passages in the valve become plugged up so that the whole valve must be taken apart and cleaned.

Since the action of the reducing valves depends upon the reduced pressure, and the power available to operate them depends, in consequence, upon the amount of the reduced pres-

sure, it has been found desirable to build each valve for a given range of reduced pressures. When the reduced pressure is very small, extra large diaphragms must be fitted, and the valve proper must usually be of the balanced type, so that the influence of the high-pressure steam upon the valve action may be reduced to a minimum. Some types must be provided with sets of several springs in case the reduced-pressure range of operation is to be great. These various factors must all be given considera-

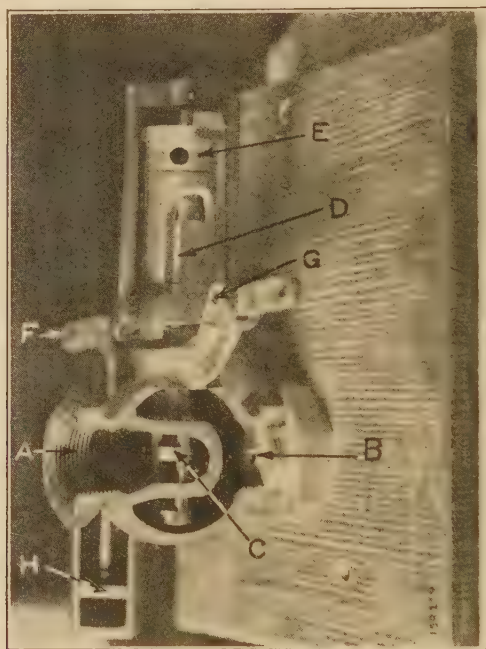


FIG. 46.—A pressure-reducing valve for steam. (Courtesy, Forest Products Laboratory.)

This valve is used principally where the flow of steam is continuous. Steam enters at A, passes through the balanced piston valve C, and out at B. The reduced pressure acts against the bottom of the piston D, which slides up and down in the cylinder E in response to changes in the reduced pressure. The adjustment of the valve for different pressures is accomplished by hanging weights on the end of the lever F, which is pivoted at G. The dashpot H aids in preventing surging of the piston and in evening out its motion.

tion in the selection of the reducing valves for any particular installation. Several types of reducing valves are shown in Figs. 44, 45, 46, and 47.

The intelligent manipulation of reducing valves frequently assists materially in maintaining good temperature control in the kilns. The steam pressure may be so adjusted that it is just slightly more than enough to keep the desired temperature with

the regulating valves wide open. Excessive temperature rise may thus be prevented and the coils kept full of steam most of the time. In hand control, this arrangement is unusually sensitive, since a comparatively large change in the setting of

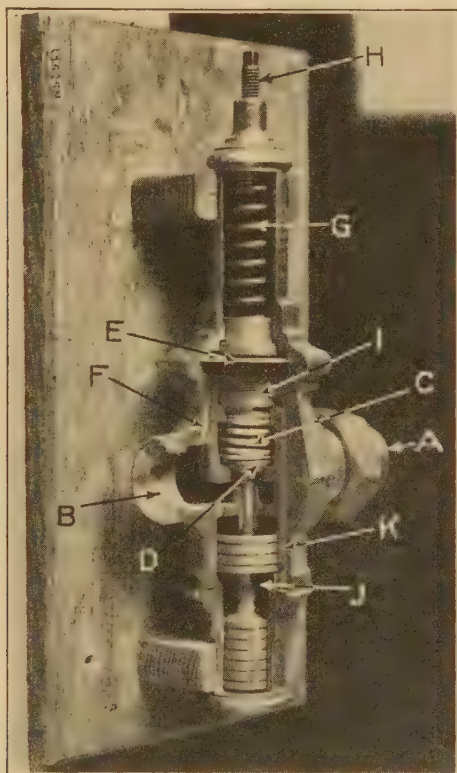


FIG. 47.—A pressure-reducing valve for steam. (Courtesy, Forest Products Laboratory.)

A very high-grade valve designed for a wide range of conditions and adapted to open and close very positively. High pressure steam is used to open the valve, and the low pressure steam operates a small pilot valve controlling this high pressure steam. Steam enters at *A* and leaves at *B*. High pressure steam and the spring *C* normally tend to keep the main valve *D* closed. The reduced pressure operates on the under-side of the metal diaphragm *E* through the passage *F*, its pressure being resisted by the spring *G*, which is adjusted by the screw *H*. When the reduced pressure is too low, the diaphragm is down and a small pilot valve in the bushing *I* is open, permitting high pressure steam to pass to the space *J* through the passage *K*. This steam then opens the main valve *D*, building up the reduced pressure until the diaphragm *E* is lifted and the pilot valve closed. The pressure in *J* drops rapidly then, and spring *C* seats the main valve again.

the hand valve makes only a small change in the amount of steam supplied, the hand valve being comparatively wide open. If the kiln is provided with automatic control, the control valve is located on the kiln side of the reducers between the hand-

operated shut-off valve and the valves on the individual heating-coil units.

66. Condensation Control Traps.—Steam imparts its heat mainly through condensation. Therefore, the water of condensation must be removed from heating coils or they will fill up with water and become cold. Various devices are used to remove water from steam coils, including several patented "systems." In most dry kilns steam traps are used. They are so called because they allow the escape of the water but trap the steam. A number of types are in use, but they may all be divided into two general classes: (1) those depending upon temperature for their operation; and (2) those depending upon the weight of the accumulated water.

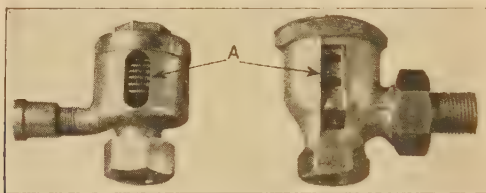


FIG. 48.—Thermostatic air valves. (Courtesy, Forest Products Laboratory.)

The bellows *A* are filled with a volatile liquid and expand with rise in temperature because of the increased vapor pressure of the liquid. The valves are open when cold, permitting the escape of air, but they close as soon as the hot steam strikes them. Valves of this type are usually limited to 25 pounds pressure.

(a) *Thermostatic Traps.*—The first class is known as "thermostatic." Most thermostatic traps have an operating bellows or diaphragm filled with oil or some volatile liquid. One end of the bellows is attached to a valve stem and valve; the motion of the bellows in response to temperature changes opens and closes the valve. Figure 48 shows two thermostatic air valves which operate on the same principle. The trap is connected to the lowest point in the heating system, so that the water will drain readily to it. The operation is as follows: When steam is first turned into the coils, they are cold and full of air, and the trap is cold and open. As the steam enters, it displaces the air, which is driven out through the open trap. A certain amount of steam is condensed, and the water of condensation flows to the trap, cooling slightly as it goes. The water also passes through the trap, which is warmed by the water and in consequence closes partially through the movement of the bellows which results from the increased pressure of the heated liquid. The

trap will remain partly open until all the air and water have been blown out and steam starts blowing through. The higher temperature of the steam causes a further expansion of the bellows and a complete shutting off of the trap. A screw adjustment is usually provided so that the trap may be set for various steam temperatures (the temperature of saturated steam increases with the pressure). After the trap has closed, condensation begins to accumulate back of it, and the trap begins cooling again. Eventually, it will cool enough to allow the valve to open and the condensation to be blown out. Thus the cycle is repeated. While it is not absolutely necessary, it is desirable, to locate thermostatic traps in the operating room because they will be under the supervision of the operator and there they will be more sensitive, since they will cool more quickly than if they are located in the hot kiln.

Thermostatic traps operate very successfully on certain kinds of dry-kiln service if the proper types are used and the installation is properly made. The range of steam pressure through which a given thermostatic trap will operate is definitely limited; within this range, adjustment must be made to secure free venting of the water without loss of steam. For low-pressure work these traps are very satisfactory. A number of makes are available in a range of sizes, and the cost is low enough so that, when the coils are split up into units, a separate trap can be fitted to each unit and interference among the different units avoided. For high-pressure work, and where the steam pressure in the coils fluctuates a great deal, thermostatic traps have not yet been adopted to any appreciable extent. Thermostatic traps should always be installed with strainers or sediment traps, so that dirt and scale will not lodge on the valve seat. Figure 49 illustrates a thermostatic condensation controller of a type which will operate successfully under high pressures but only when the steam pressure in the coils is kept uniform. It will not work well on thermostatically controlled coils because of the large variation in pressure.

(b) *Gravity Traps*.—A number of types of traps which operate through the weight of the water of condensation are used on dry kilns. Among these may be mentioned tilt traps, bucket traps, and float traps. A bucket trap is illustrated in Fig. 50 and a float trap in Fig. 51. In all of these the water of condensation flows into a receptacle within the trap and by its weight or buoy-

ancy opens a valve, allowing the water to be blown out, after which the valve returns to its closed position.

Tilt traps are made in two styles, "return" and "non-return." The return traps are so constructed that the water discharged from them may be returned direct into the boilers if the traps are located above the boiler water level. The trap, as it tilts,

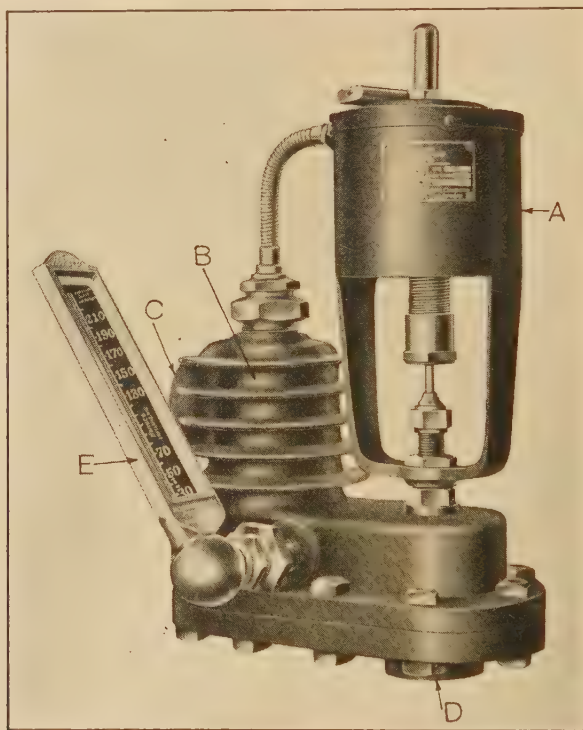


FIG. 49.—A self-contained condensation controller or trap. (Courtesy, American Schaeffer and Budenberg Co.)

This is a thermostatic trap consisting of a self-contained thermostat A, combined with a condensation chamber B. The bulb of the thermostat is mounted in this chamber and operates the valve with changes of temperature in it. The condensate enters at C and passes out at D. The valve remains open until steam starts to flow, and then shuts off because of the rise in temperature. The industrial thermometer E indicates the functioning of the trap and assists in making the adjustments.

opens a connection which permits live boiler steam to enter it, equalizing the pressure and allowing the water to run into the boiler by gravity. When the trap has been discharged and returns to the filling position, this connection is closed and the trap vented into the heating system. Non-return tilt traps can discharge only against a pressure less than that in the coils.

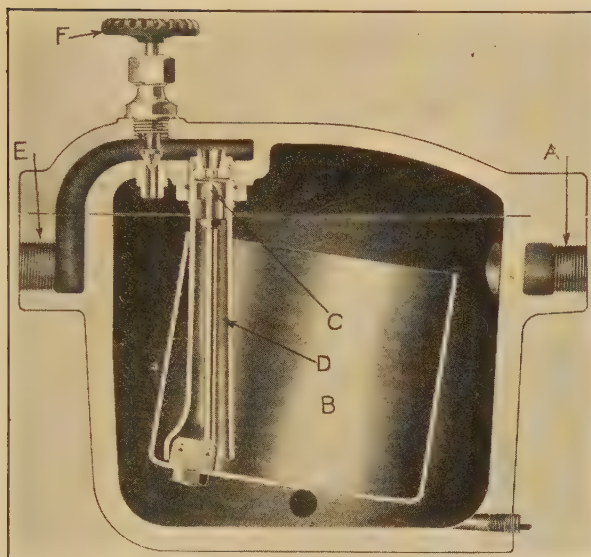


FIG. 50.—A bucket steam trap. (Courtesy, Crane Co.)

This type is also frequently called an open float steam trap. Condensation enters from the heating system at the point *A*, flowing to the bottom of the trap and surrounding the open float *B*. When the water rises high enough, it overflows into the bucket *B*, eventually filling it sufficiently to tilt it downward into the position shown. In this position the valve *C* is drawn away from its seat, and the pressure in the system forces the water upward through the pipe *D*, past the valve *C*, and out through the outlet *E*. After a sufficient amount of water has been blown out, the buoyancy of the bucket causes it to rise, closing the valve *C*. This type of trap can be so balanced that the level of the water in the bucket never descends low enough to allow steam to escape from the trap. The bypass or blow-off *F* provides a ready means of blowing out air or for assisting in the removal of excessive amounts of condensation, especially when the system is first started up.

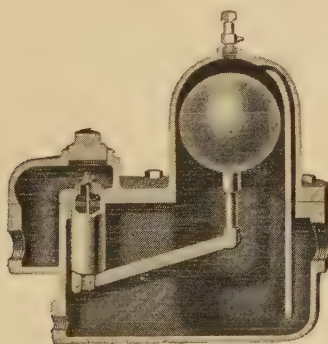


FIG. 51.—Steam trap of the float type. (Courtesy, Wright-Austin Co.)

As the trap fills with water of condensation, the float rises until it opens the small valve to which it is linked. Pressure of the steam forces the water out through this valve until the level of the water falls sufficiently to close the valve again.

A non-return tilt trap is illustrated in Fig. 52. All traps must be inspected at intervals to be sure that they are functioning, and those of the gravity types should be provided with a by-pass to enable the coils to be blown out when steam first enters or when they are air bound.

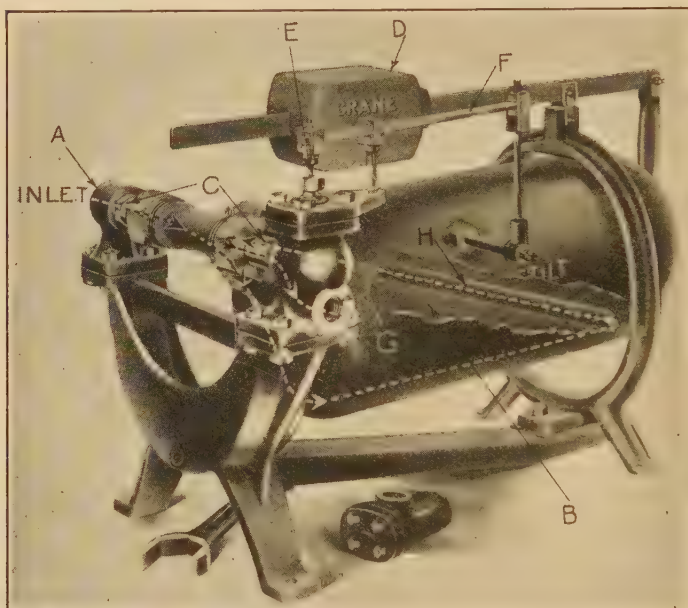


Fig. 52.—A tilting steam trap. (Courtesy, Crane Co.)

The operation of this trap is as follows: Condensation from the coils enters the trap at the point *A* and follows the dotted line into the body *B* of the trap. This is pivoted upon trunnions *C* and is provided with an adjustable counterweight *D* so balanced that when a sufficient amount of water has entered the trap the body tilts downward from the position shown. In tilting, it operates the small valve *E* through the lever *F*, opening the discharge passage *G*. As soon as this is opened, the pressure within the system forces the water upward through the pipe *H* and out of the trap through *G*. As soon as the water has all been expelled, the counterweight *D* returns the trap to the filling position.

(c) *Check Valves in Connection with Traps.*—When the heating coils are broken up into units, and several units are connected to a single trap, the steam will back up into those units which are shut off and cause uneven heating unless a valve is placed in the drain from each unit. These valves are usually of the swing-check type. They must be inspected occasionally, since they have a habit of sticking and thus preventing their respective units from functioning.

For low-pressure work an automatic air valve should be provided near each trap which depends for its action upon the

weight or buoyancy of the condensate, since these traps will not vent air. If the trap itself is of the thermostatic type, depending for its action upon the temperature of the steam and water, no air valve is needed.

67. Air Valves.—Automatic air valves all operate thermostatically; they remain open until a definite temperature is reached and then automatically close through the action of some element, such as a metal bar or a liquid-filled capsule, which expands with increase in temperature (Fig. 48). This action permits the cold air to be blown out of the coils and prevents the passage of the hot steam. Adjustment is usually provided for by an adjusting screw similar to that in thermostatic traps. Other things being favorable, air valves should be placed near the bottom of the coils, since the air is heavier than the steam and, consequently, tends to sink; yet they should be mounted on fittings projecting from the top of the drip pipes or drains, otherwise they will become water bound. The working range of air valves is limited and, therefore, a type should be selected suitable for the pressures to be used. When air valves are not installed, other means must be provided for venting the air. This is usually accomplished by a hand-operated by-pass located at the trap; or, in tilt traps, by the simple expedient of tilting each trap by hand and holding it down until the coils are free from air. Once thoroughly hot, high-pressure coils give little or no trouble from air binding.

68. Vacuum Pumps on Drain Lines.—Occasionally, a battery of kilns operating on low-pressure steam is equipped with a vacuum pump. The function of a vacuum pump is to provide speedy relief of air and water from the coils and to return the water to the boilers. One pump can serve a battery of kilns, each heating coil being connected to the pump suction main through a thermostatic trap. The suction of the pump helps greatly to remove the air and water, but dependence must still be placed upon traps, since the pump will not work properly without them.

The added expense of installation and operation of a vacuum pump is generally not considered worth while for the usual run of kiln installation.

69. Thermometers. (*a*) *Indicating Thermometers.*—Temperature-measuring instruments, or thermometers, may be grouped into two classes, “indicators” and “recorders.” Indi-

cating thermometers for kiln work are almost invariably of the mercurial type, although sometimes alcohol-filled thermometers are used. Many kinds of mercurial thermometers are on the market, and care must be used in their selection. The very cheap ones, commonly called "household goods," are to be avoided, since they are neither accurate nor reliable. These have separate scales, usually stamped on metal and attached to the case. A number of the better grades also have separate scales, but the highest-grade thermometers all have the graduations etched on the glass stem. These thermometers can be secured either plain or with metal protecting cases. Figure 53 shows an etched-stem thermometer in a protecting case, and Fig. 54 shows how two such thermometers may be mounted together in the form of a sling psychrometer or wet-and-dry-bulb thermometer. Occasionally, it is possible or desirable to insert the thermometer through the wall of the kiln, the bulb being inside and the scale outside. Industrial-type thermometers are well adapted for this purpose. These usually are provided with a brass extension tube surrounding the bulb and part of the stem and a weatherproof brass casing with a glass face protecting the scale. The extension tubes may be made 3 feet or longer, and the stem fitted on at almost any desired angle. A right-angled stem is, for instance, desirable where the extension tube projects horizontally into the kiln, since it permits the scale to be vertical and, therefore, most easily read. Figure 55 illustrates a right-angled stem, industrial-type thermometer.

(b) *Recording Thermometers.*—Recording thermometers used in kiln work are almost invariably of the extension-tube type and are provided with one-day or seven-day clock movements. In recorders of this type the sensitive element or bulb is located in the kiln and is connected to the instrument, located outside of the kiln, by a capillary tube of suitable length. This tube is usually protected by a flexible armor and ends in a spring capsule in the case. This capsule may be of any one of several different types, all of which are flexibly constructed so that changes in internal pressure produce a movement of the capsule which is transmitted through a series of levers to a pen arm which moves across a revolving chart operated by the clockwork, producing a graphic record of the temperature in the kiln.

There are three distinct types of recording thermometers, the differences being in the material used for filling the bulbs.

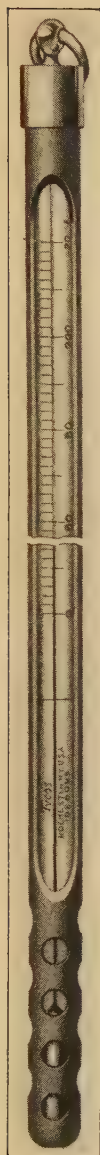


FIG. 53.

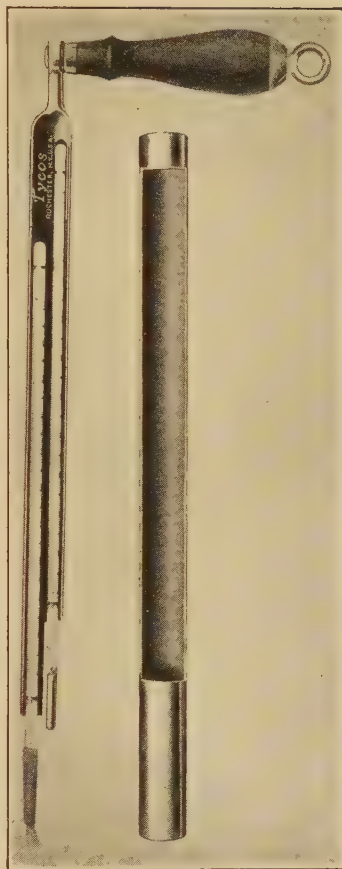


FIG. 54.



FIG. 55.

FIG. 53.—Etched-stem chemical thermometer with case. (Courtesy, Taylor Instrument Co.)

A very useful thermometer for calibrating recorders and for general testing work.

FIG. 54.—Sling psychrometer. (Courtesy, Taylor Instrument Co.)

Here illustrated to show the two etched-stem chemical thermometers used. This instrument differs from the ordinary wet-and-dry-bulb hygrometer in that it can be whirled about the handle, to produce the required air circulation.

FIG. 55.—Industrial-type thermometer. (Courtesy, Taylor Instrument Co.)

This may be secured in a wide variety of ranges and tube lengths; in addition to the straight stem type it can be had in right-angle and 45° types as well as one with an angle of about 22° between stem and scale. For kiln use, the threaded union is not necessary.

These three types are commonly known as "mercury-filled," "gas-filled," and "vapor-filled." The selection of the type to be used for any specific purpose depends upon the accuracy desired and the surrounding conditions. In dry-kiln work, both the tube and the case are liable to be subjected to quite wide

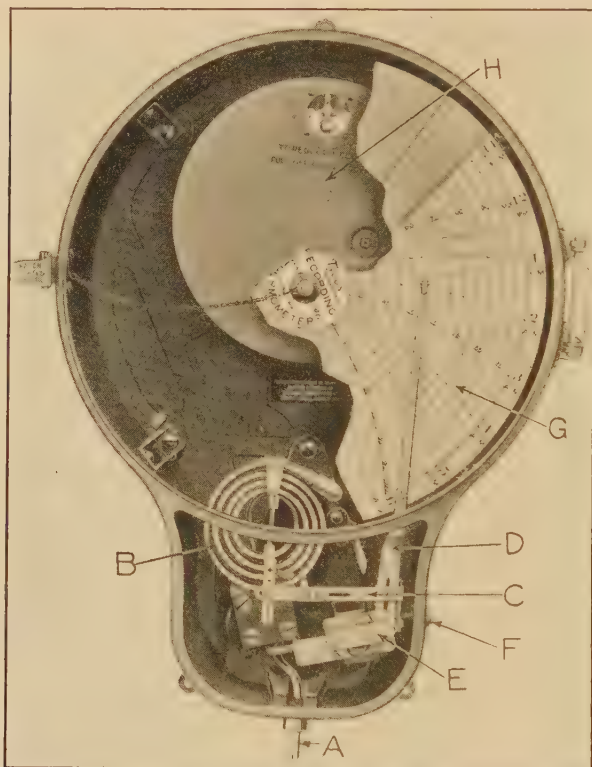


FIG. 56.—A recording thermometer. (Courtesy, Taylor Instrument Co.)

Variations in the vapor pressure of the liquid in the bulb of the instrument (not illustrated), caused by temperature changes, are transmitted through the tube A to the flat spiral element B, which is made of flattened tubing. These variations cause the free end (the outer one) to move back and forth. The movement is transmitted through the link C to the pen arm D, the pen making a record on the chart G. The chart is rotated by means of the clock H. It is customary in kiln work to use either one-day charts or seven-day charts. The pen can be set or adjusted from the outside by means of a key fitted to the post F. Turning this key alters the length of the arm E, changing the setting of the pen.

variations in temperature. These variations in tube and case temperatures have an important influence upon the accuracy of the instrument, especially in the "mercury-filled" and "gas-filled" types. In these the temperature actually recorded is a combination of the bulb temperature, the tube temperature, and

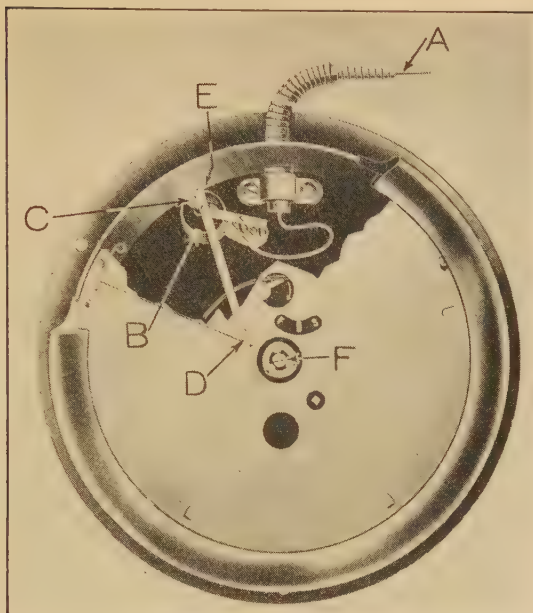


FIG. 57.—A recording thermometer. (Courtesy, Foxboro Co.)

This instrument, like that shown in Fig. 56, is operated by changes in pressure produced in the temperature-sensitive bulb. The hollow spiral *B* is in the form of a helix, and the motion of the upper end is transmitted to the pen arm *D* through the bar *C*. The instrument is set by turning the screw *E* which connects *D* and *C*. It will be noted that this recorder has the pen mechanism in the top and the clock below. The main pillar is provided with a quick locking device *F*, which permits quick removal and replacement of the charts.

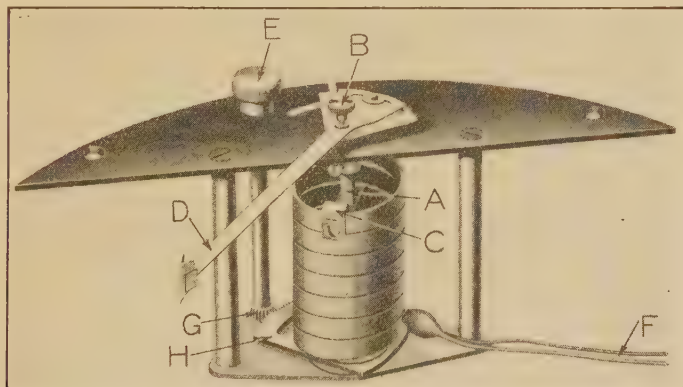


FIG. 58.—A helical pressure-sensitive element. (Courtesy, Brown Instrument Co.)

This general type of element is used in several kinds of recording thermometers. It is made of flattened tubing of spring brass or steel, and expands and contracts with changes in pressure. The lower end is fixed and connected with the extension tube, *F*, and the motion of the upper end is transmitted to the pen arm *D* through the arm *C* and the pillar *A*. Screw *B* regulates the tension or pressure of the pen upon the chart.

Setting of the pen is accomplished by turning the nut *E*, which, through gears *G* and *H*, turns the entire element. If the instrument should develop an error of constantly increasing or decreasing size from one end of the range to the other, the arm *C* can be slid around on the helix, thus changing its effective leverage.

the case temperature. Variations in any one of these three temperatures will change the reading of the instrument. Figures 56 and 57 illustrate two makes of recording thermometer, and

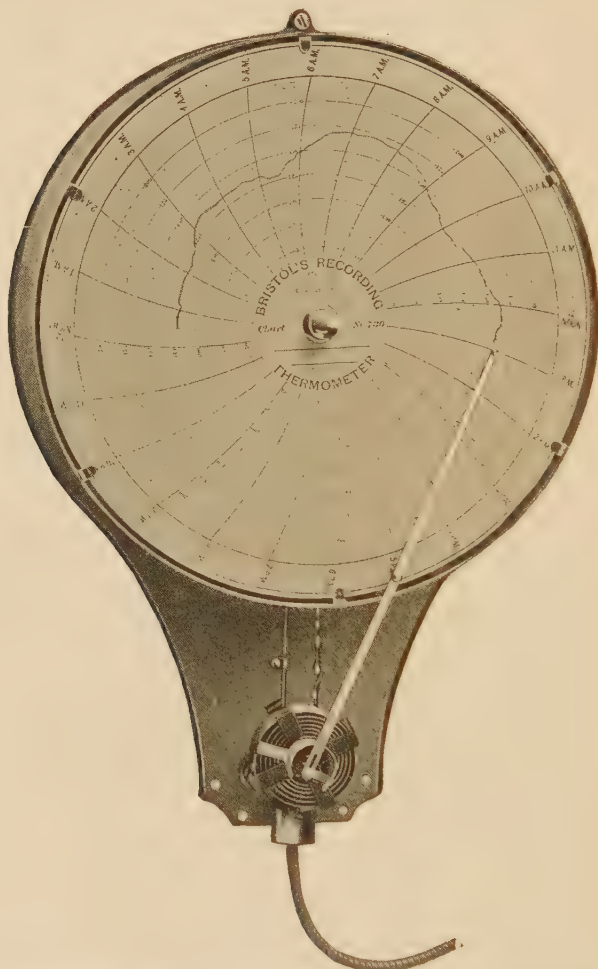


FIG. 59.—Gas-filled recording thermometer compensated for variations in case temperature. (Courtesy, Bristol Co.)

The small helix, which appears in the illustration as a $\frac{3}{4}$ circle directly under the lower end of the recording pen and directly in front of the main helix, acts in opposition to the main helix, and is of such size that it just neutralizes the pen-movement caused by temperature changes in the main helix.

Fig. 58 shows the spring helix used in the third type. Figure 59 illustrates a gas-filled recording thermometer which has been compensated for variations in case temperature by a small

reverse-acting helix which appears as a three-fourth circle directly under the lower end of the pen arm and in front of the principal helix. The vapor-filled instrument is nearly free from errors due to case and tube temperatures, since the bulb is partially filled with volatile liquid, and the pressure of the gas or vapor in the tube and capsule is the vapor pressure of the liquid in the bulb at the bulb temperature.

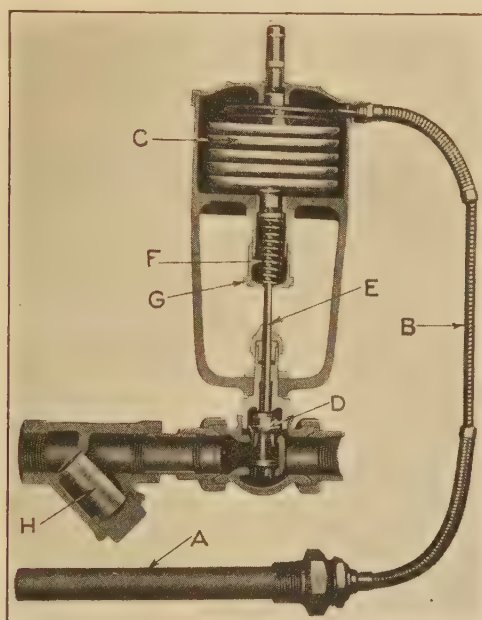


FIG. 60.—A self-contained thermostat. (Courtesy, American Schaeffer and Budenberg Co.)

This instrument does not require compressed air to operate it, but depends entirely upon the pressure changes produced by changes in the temperature of the bulb A. The pressure is transmitted through the tube B to the diaphragm motor C, tending to press down the balanced valve D and its stem E. This is resisted by the spring F, the pressure of which can be regulated by the spring housing G for any desired temperature. When the temperature rises beyond this point, the diaphragm motor closes the valve; when it falls below this point, the spring opens it. The strainer H prevents chips and dirt from entering the valve and causing leakage. The union connection on the bulb is not needed for dry kiln work.

Weekly charts are satisfactory for most purposes; it is desirable to use large charts, however (10 or 12 inches in diameter). Unfortunately, the divisions on the charts of most vapor-filled instruments are not uniform because the vapor pressure does not vary in direct proportion with the temperature. The divisions are further apart at the higher end of the scale. One manufacturer has designed a cam movement to compensate for

this lack of uniformity and to produce a pen movement practically uniform throughout the range of the instrument.

70. Thermostats. (a) *Self-contained Thermostats.*—Automatic control of the kiln temperature is essential for accurate results and the fastest drying consistent with proper quality.

In general, there are two types of equipment for automatic temperature control in more or less common use in dry kilns. These are known as "self-contained" and "air-operated," respectively, the instruments usually being of the extension-tube type. The self-contained thermostats are operated by the direct

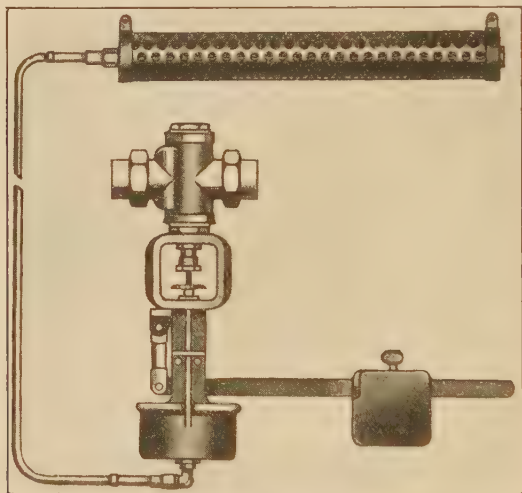


FIG 61.—A self-contained thermostat. (Courtesy, Powers Regulator Co.)

This instrument operates upon the same principle as the one illustrated in Fig. 60, differing from it, however, in having a sliding weight for temperature adjustment in place of a spring. The temperature-sensitive bulb is of unusually large size and is fluted so as to expose as large a surface as possible to the air. The perforated cylinder surrounding the bulb serves as protection.

action of vapor or liquid pressure, through a diaphragm motor, upon the valve stem. The action is very similar to that of the recording thermometers already described. There is a large bulb in the kiln connected by means of a capillary tube to a diaphragm or capsule in the head of the valve body which is located in the steam line. The changes in temperature in the kiln cause changes in the pressure inside the bulb, which, in turn, cause pressure changes in the diaphragm motor, resulting in an

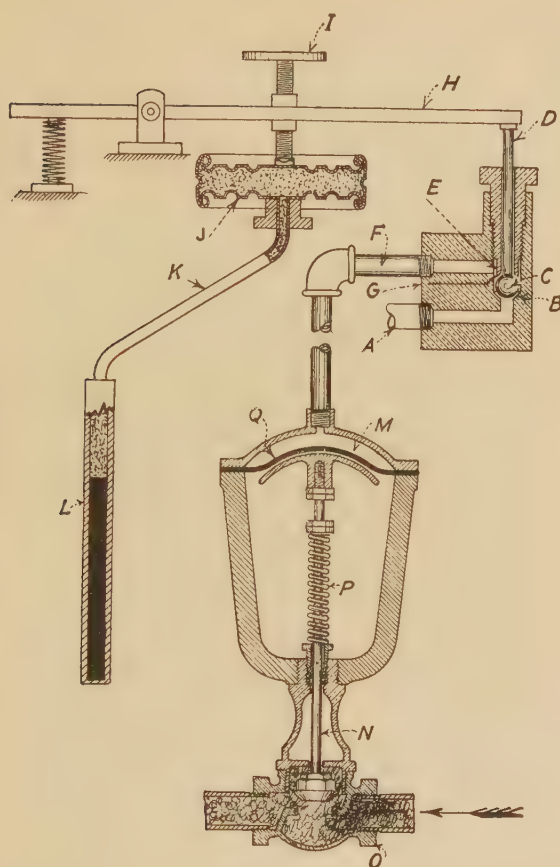


Fig. 62.—Section of air-operated thermostat and diaphragm motor valve.

Opening and closing of the diaphragm motor valve is accomplished through the medium of compressed air, at about 15 pounds pressure. When the air is admitted to the chamber *M*, it forces downward the diaphragm *Q* and with it the valve and valve stem *N*, the valve seating in the valve body *O* and shutting off the flow of steam. When the air pressure is released, the spring *P*, aided by the steam pressure, acting on the under-side of the valve, raises the valve and permits the steam to flow.

The supply of air to the diaphragm motor valve is controlled by a small valve *C*, as follows: When the temperature of the bulb *L*, which is in the kiln, rises, in response to increased kiln temperature, increased pressure is transmitted through the capillary extension tube *K*, to the spring capsule *J*, which expands, the top of which rises as a result, carrying with it the adjusting screw *I* and the lever *H*. This allows the air pressure from the supply line *A* to raise the valve *C* and the valve stem *D*. The air then flows around the valve through the pipe *F*, into the chamber *M*, shutting off the steam. When the temperature of the bulb *L* falls, the reverse action takes place, and the valve *C* is seated, shutting off the air supply to the diaphragm motor valve. The pressure of the air in the chamber *M* is then relieved through the leakage of air around the valve stem *D*, which is made a loose fit for this purpose. As the pressure is relieved, the valve and valve stem *N* rise and permit the flow of steam.

up-and-down movement of the valve stem, which is attached to the motor, and a consequent change in the valve opening. The valve itself is usually of balanced construction, to provide ease of movement. A counter force or pressure is provided by means of an adjustable spring or sliding weights, and the instrument is set for the desired temperature by changing the tension of the spring or the position of the weights. Figures 60 and 61 illus-

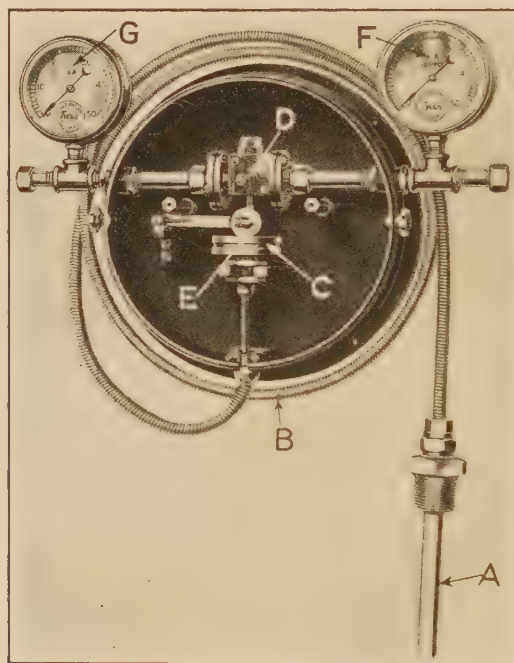


FIG. 63.—An air-operated thermostat showing interior construction. (*Courtesy, Taylor Instrument Co.*)

A is the bulb, *B* the connecting tube, *C* the spring capsule, *D* the air valve, and *E* a cam which is rotated to set the instrument for the desired temperature. *F* and *G* are the air pressure gauges. The union connection on the bulb is not needed for dry kiln work.

trate two types of self-contained thermostats. The great advantage of the self-contained thermostat lies in the fact that no auxiliary source of power is required for its operation. This type is not so sensitive, however, as the air-operated type. The manufacturers usually claim regulation within 2° either way from the temperature for which the instrument is set. Variations in the temperature of the diaphragm motor affect the accuracy of these thermostats. Air-operated instruments usually control the temperature with a variation of only 1° either way.

Self-contained thermostats do not give satisfactory results when used with automatic humidity regulation because their control of temperature is not sufficiently accurate.

(b) *Air-operated Thermostats*.—The air-operated instruments are usually provided with a small bulb placed in the kiln and connected to a spring capsule in the instrument by means of a capillary tube. Figure 62 illustrates diagrammatically the operation

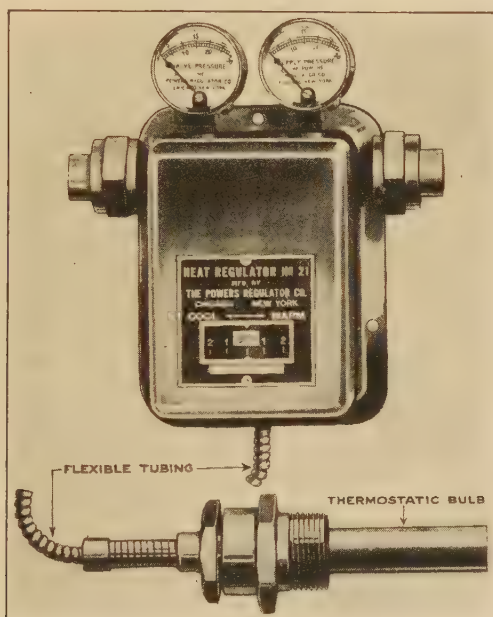


FIG. 64.—An air-operated thermostat. (Courtesy, Powers Regulator Co.)

This instrument differs from most of the other air-operated thermostats in that an approximate temperature scale forms an integral part of it. This scale assists materially in making the initial temperature setting. The operator can set the dial at the desired temperature and know that the instrument will operate within a few degrees of that temperature. This instrument also provides against damage to the valve and other parts from excessive temperature. The union connection on the bulb is not needed for use in dry kilns.

of this type of instrument. The movement of the capsule top, in response to temperature changes in the kiln with consequent pressure changes in the bulb, tube, and capsule, is transmitted through levers to a small valve connected on one side to a supply of compressed air at a pressure of about 15 pounds per square inch and on the other side to a diaphragm motor valve on the steam main. Sometimes a bimetallic system is used in place of the capsule to operate the air valve. This small valve is so arranged,

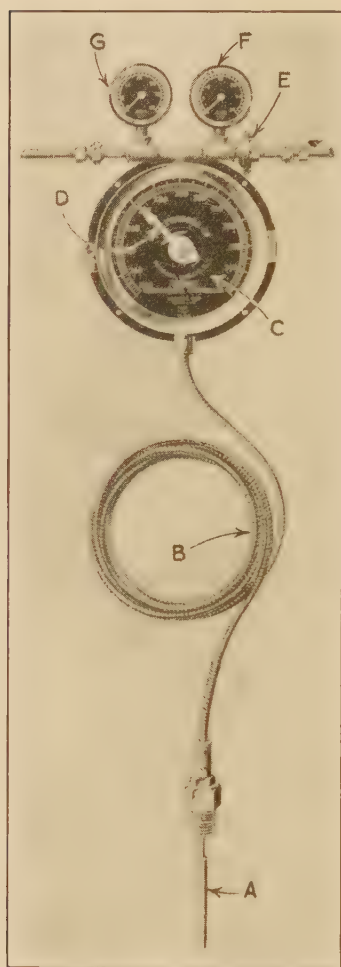


FIG. 65.—An air-operated thermostat. (Courtesy, Foxboro Co.)

Pressure changes in the bulb *A* are transmitted through the tubing *B* to the capsule in the case *C*. The pointer *D* serves to set the instrument for the desired temperature. *E* is an air filter and *F* and *G* are air pressure gauges to show the supply pressure and the pressure on the diaphragm. This instrument is usually furnished to operate with reverse-acting diaphragm valves; that is, valves in which the air pressure opens the valve instead of closing it.

The union connection on the bulb is not needed for use in dry kilns.

in direct-acting instruments, that, as the temperature rises, air pressure is admitted to the motor head of the diaphragm valve, thus forcing the diaphragm down, closing the valve, and cutting the steam off from the kiln. As the temperature falls, the air pressure is shut off, means of escape is provided for the air in the motor valve, and the valve is opened by means of a spring, admitting steam to the kiln. Figures 63 and 64 illustrate two makes of direct-acting thermostats. In reverse-acting instruments, the diaphragm valves are so constructed that the air pressure opens them and the springs close them, which is just the reverse of the direct-acting valves. The air valve must, of course, be modified accordingly. Figure 65 illustrates a reverse-acting thermostat. The advantage of the reverse-acting type lies in the fact that failure of the air supply causes the valves to shut, preventing a dangerous rise in temperature. The same effect may be secured in a battery of direct-acting thermostats by putting a single reverse-acting valve in the steam main, connecting it directly to the air supply. Both types are equipped with adjustments for securing the proper temperature.

In the type of reverse-acting thermostat illustrated in Fig. 65 the motion of the spring capsule is not transmitted directly to the air valve but operates a small strip of metal, the movement of which opens and closes a small air port technically known as an "air-leak." When the temperature rises, the strip of metal closes the air-leak, and pressure is built up in a small flexible capsule or bellows, expanding it and moving the air valve which is direct-connected to it. This movement of the air valve shuts off the air from the diaphragm motor valve in the steam line, which then closes, shutting off the steam. When the temperature falls, the air-leak is opened, the small bellows collapses, the air valve is moved in the opposite direction, and air is admitted to the diaphragm motor valve which opens and admits steam to the coils.

71. Thermometers and Thermostats Combined.—Various combinations of air-operated recording thermometers and thermostats mounted in a single case can be had. Double thermostats, consisting of two separate instruments in the same case, are very convenient when both temperature and humidity are to be regulated, but are no better, from the operating standpoint, than two single instruments.

The combination of a recording thermometer and a thermostat in the same case and operated by the same bulb, tube, and capsule is very convenient and is appreciably cheaper than two separate instruments. A double combination of this type is now available—a two-pen recorder and a double thermostat all in one case and operated by two bulbs, two tubes, and two capsules. This combines the necessary temperature and humidity-control instruments in one compact unit. These instruments are called “recorder regulators.” Figure 71 (Chap. VII) illustrates a double-pen instrument of this type.

72. Time-temperature-humidity Controllers.—Almost all drying schedules call for an increasing temperature and a decreasing humidity as the run proceeds. These changes are usually secured by hand adjustment of the thermostats from time to time. Several instruments are provided, however, with means for doing this automatically. In these, a clockwork rotates a disc cam, upon the profile of which the adjusting lever rides, changing the adjustment in accordance with the profile of the cam. By having a sufficient number of cams, each cut for a particular schedule, and sufficient latitude in the clock gearing (so that the speed of rotation of the cam may be varied through wide limits), any desired drying schedule may be followed. The changes will, of course, follow a rigid time schedule, which in itself is undesirable since no two kiln charges of lumber will dry in the same time. This feature, however, can be remedied by stopping the clock at intervals, or speeding it up, as the case may require. A time-temperature-humidity controller is illustrated in Fig. 77 (Chap. VII). Single instruments are called “time-temperature” controllers and double ones “time-temperature-humidity” controllers.

73. Temperatures Recommended.—The temperature to be used in a dry kiln depends upon the kind of lumber to be dried, its thickness, the purpose for which it is to be used, and its moisture content.

In general, it is more economical to use as high a temperature as the lumber will stand since heat hastens the transfusion of moisture from the interior to the surface. It also is more economical to operate at high temperatures on account of the greatly increased capacity of the air for moisture. For stock in which a maximum amount of strength is essential, as for air-planes, handles and spokes, and athletic and sporting goods,

it is best to keep the temperature below 150°F. during the drying process, except for occasional steaming. Temperatures somewhat higher than 150°F., if maintained for any length of time, are liable to affect the strength of the material even if other conditions, such as humidity and circulation, are favorable.

For other purposes, in which a slight reduction in strength is not detrimental, higher temperatures may be used, provided the wood does not check seriously, collapse, or deteriorate in some other way.

For the ordinary commercial uses of softwoods, much higher temperatures may be maintained. Yellow pine, spruce, Douglas fir, and other coniferous woods may even be dried at temperatures around 212°F. without serious injury for most uses, provided the humidity is regulated accordingly.

Green oak and other heavy hardwoods, on the other hand, must be dried very carefully at comparatively low temperatures, or considerable depreciation may result.

In drying green lumber it is necessary to keep a comparatively low temperature until the fiber-saturation point is passed, after which there is no danger of collapse and less danger of severe casehardening and checking. In kiln drying air-dry lumber, temperatures suitable for its moisture content should be used just as if it had been dried to that condition in the kiln.

Tables showing what temperatures should be used in drying various kinds of woods will be found in Chap. IX.

74. Heat Calculations.—The calculation of the various thermal requirements, such as the amounts of heating surface and steam required, cannot ordinarily be done with any degree of accuracy, even by the most accurate and detailed methods available, principally because there are so many variable factors which are not definitely known for any given installation. Simple “rule-of-thumb” methods giving reasonably good results are, therefore, common. A very simple formula for calculating heating surface, and one which provides ample surface for quick heating of the kiln in starting up, follows:

$$W \times H \times K = R$$

W = width of the kiln above the rail, in feet.

H = average height of the kiln above the rail, in feet.

K = constant, from Table VIII below.

R = radiation surface required per linear foot of kiln.

TABLE VIII.—CONSTANT "K" FOR CALCULATING AREAS OF HEATING SURFACES

Maximum temperature, F.° and 25 per cent humidity	Pounds steam pressure			
	2.5	7	30	80
120	0.10	0.075		
130	0.166	0.130	0.090	0.055
145	.....	0.166	0.125	0.085
160	.....	.....	0.166	0.120
180	.....	.....	.....	0.166

This formula gives the radiation per linear foot of kiln.

To find the number of pipes required:

$$\frac{R}{A} = P.$$

A = area of 1 linear foot of pipe.

P = number of pipes required in cross-section of kiln.

This formula is based on a circulation of 60 feet or less per minute across the coils. In blower kilns with rapid circulation over the heating surface, the amount of heat delivered per unit of heating surface goes up as the circulation increases; hence, not so much coil is needed.

Table IX is given for convenience in figuring pipe areas.

TABLE IX.—SQUARE FEET OF RADIATING SURFACE PER LINEAR FOOT OF PIPE

DIAMETER OF PIPE, INCHES	RADIATING SURFACE PER LINEAR FOOT, SQUARE FEET
$\frac{3}{4}$	0.275
1	0.346
$1\frac{1}{4}$	0.434
$1\frac{1}{2}$	0.494
2	0.622
$2\frac{1}{2}$	0.753
3	0.916

Assume, for instance, a kiln 20 feet wide and 12 feet high above the rails, a desired temperature of 180°F., and 80 pounds of steam pressure available. K for these conditions is 0.166 and R =

$20 \times 12 \times 0.166 = 40$ square feet per foot length of kiln. If 1-inch pipe be used, $A = 0.346$ and $P = \frac{40}{0.346} = 116$ pipes.

This amount of radiation will be satisfactory for a well-constructed kiln and average normal outside conditions, but the rule does, of course, not make provision for unusual heat losses from the kiln building.

75. Boiler Capacity Required.—The amount of boiler horsepower required for any given drying job can be estimated on the basis of the amount of water to be evaporated from the lumber in a given time and the efficiency of the drying operation. This efficiency depends upon the time required to do the drying and the heat losses through the kiln. Obviously, where the drying rate is very slow, and the kiln has to be kept hot for a very long time while a small amount of moisture is removed from the wood, the heat efficiency will be very low. The method of calculating steam consumption in boiler horsepower is to determine the amount of moisture to be removed in an hour, divide this by the efficiency of the drying operation, and then divide by 34.5 (the number of pounds of water evaporated per hour, from and at 212°F. for 1 boiler horsepower). Assume a softwood drying operation in which 10,000 pounds of water are to be removed in an hour and the efficiency of the drying operation is 60 per cent (1 pound of water evaporated in the boiler, from and at 212°F., will evaporate 0.60 pound of water from the lumber and take care of heat losses from the kiln while doing so). The amount of water to be evaporated in the boiler (from and at 212°F.) is then $\frac{10,000}{0.60} = 16,667$ pounds per hour, and the boiler horsepower required will be $\frac{16,667}{34.5} = 486$ horsepower.

It should be noted that the amount of steam used will be somewhat less than 16,667 pounds per hour, since 1 pound of steam at boiler pressure contains more available heat than that required to evaporate 1 pound of water from and at 212°F. This does not, however, affect the accuracy of the calculation, since the boiler rating is arbitrarily figured on the amount of heat required to evaporate the water. This method of rating simplifies the calculation in this instance. The greatest source of error lies in the efficiency of the drying operation, and little accurate information is available on this. It can, theoretically,

be calculated on the basis of the heat loss from the kiln; the method of doing this will be found in detail in heating and ventilating textbooks.

Experiments on various kinds of drying indicate that the kiln efficiency varies from about 65 per cent in softwood operations requiring only two or three days, to as little as 10 per cent in hardwood drying requiring six months.

CHAPTER VII

HUMIDITY AND EVAPORATION

76. Why Humidity Is Necessary in a Dry Kiln.—To one not familiar with the peculiar behavior of wood in drying it must seem paradoxical to maintain a high temperature in a kiln and at the same time maintain more or less humidity which reduces the rate of evaporation. It should be remembered, however, that the drying of lumber is not a problem of obtaining rapid evaporation, but one of obtaining a rapid transfusion of moisture from the interior to the surface without damage to the lumber. In fact, there is danger of too rapid surface evaporation from lumber in a kiln, for, as has been shown in Chap. IV, if the outer layer becomes much drier than the central part, various troubles are apt to occur.

The following are the principal reasons for keeping the air moist or occasionally steaming the lumber in a kiln:

1. To prevent or to reduce surface and end checking. Checking, as pointed out in Chap. IV, is due to the stresses caused by uneven shrinkage, which, in turn, usually is due to uneven drying. When the surface and the ends of boards dry much faster than the interior, checks usually form.

2. To prevent severe casehardening, and to aid in relieving casehardening if it does occur. The use of high humidities in relieving stresses has been explained in Chap. IV. Directions for steaming lumber will be given later in this chapter.

3. To hasten the transfusion of moisture. If the surface layers become very dry, moisture will not pass from the interior to the surface so rapidly as if the outer portion were not so dry. In some woods, dried at too low a humidity, it is common to find the surfaces dry but the interior practically green after the lumber has been in the kiln for several weeks. Of course, during the drying process the outer shell must be somewhat drier than the core, or the moisture will not move outward, but the difference should not be too great.

That moisture does not pass so quickly through very dry substances as through the same materials when they are damp may be illustrated in a number of ways. In trying to mop up water with a dry rag it will be found that it takes longer for the moisture to become absorbed than if the rag is slightly damp. This fact is still better illustrated in the use of a chamois skin for drying automobile and carriage bodies. A dry chamois skin will not do at all, because it takes up the moisture too slowly; but if it is first soaked and then wrung out, it makes an excellent absorbent. The same principle is made use of in cultivating the soil to conserve moisture when there is insufficient rainfall. The top soil is kept loose and dry, which reduces the rate at which the moisture from the lower soil comes to the surface to be evaporated, and, hence, there is less loss of soil moisture.

The reason for this is that any substance which absorbs moisture is not an absolute solid; there are spaces between the particles of which the substance is composed into which water can enter. If there is even a film of moisture extending from one particle to another, as from one thread to another in a damp rag, moisture can travel along this film; while if the substance is dry, it can pass only from one particle to another at the point where the particles are in contact. When wood fibers become very dry, all the fibrils in the cell walls are not connected by a film of water, and some are actually separated in places, producing within the cell walls checks that are visible under the microscope. The moisture cannot jump these gaps but must take a roundabout way to the surface, which reduces the rate of transfusion of moisture to the surface.

When lumber becomes very dry at the surface and the moisture does not come out so rapidly as it might, it is a common practice to admit steam to the kiln. Operators often call this "steaming to open the pores." This is not the correct term for it, since in the first place the pores do not close up as wood dries, and in the second place steaming does not open the pores any wider. Furthermore, it should be remembered that most of the moisture does not come out along the pores, but across them, in the pore walls. What steaming probably does is to moisten the walls so that a film of water extends between the particles of which the walls are made, affording a direct route along which the moisture can pass rapidly from the interior to the surface. In drying some woods, for example, Douglas fir and spruce, an

occasional steaming does not appear to hasten the drying appreciably, while in drying some others, as oak and cypress, it is decidedly beneficial.

4. To even up the moisture content. Steaming lumber at high temperatures during a kiln run tends to even up the moisture content rapidly by adding moisture to the surface layers from the steam, and dispersing the moisture at the center on account of the increased temperature—the heat penetrating more rapidly than the steam.

5. To regulate the dryness of the lumber. Another advantage of being able to regulate the humidity in a kiln is that the final dryness of the lumber can be regulated. From Fig. 11 it can be seen that at a humidity of 34 per cent and a temperature of 141°F. lumber will not dry to below 5 per cent moisture. At higher temperatures, the moisture content at equilibrium would be slightly less. Of course, it is not advisable, as a rule, to maintain a final humidity corresponding to the final moisture content desired in the lumber, but rather a little lower humidity, or the last stages of drying will be very slow. However, if one portion of the kiln charge should become suitably dry before the rest, a properly regulated humidity will keep the dry portion from becoming too dry while the wetter portion is drying.

If during a kiln run it is desirable to stop surface drying entirely, this can be done by raising the relative humidity to the necessary amount. For example, if the surface layers of the lumber have dried to 10 per cent moisture while the interior still contains 25 per cent, it would be desirable to keep the surface from becoming any drier until the interior has lost more moisture. This can be done, as indicated by the curves in Fig. 11, by maintaining the humidity as follows, assuming the temperature of the kiln to be 105, 141, or 212°F.

TEMPERATURE, DEGREES	HUMIDITY, PER CENT
105	60
141	66
212	78

Each one of these conditions will prevent the surface from becoming drier than 10 per cent; and if the circulation is good, the moisture, in excess of 10 per cent, which comes out of the interior to the surface, will be evaporated. In such cases it usually is advisable to step up the temperature, while a correspondingly high humidity is held, so as to hasten the transfusion of moisture.

The humidities for other temperatures and moisture contents can be found by proper interpolation between the curves in Fig. 11.

6. To darken sapwood. Steaming is also resorted to for darkening the sapwood in red gum and black walnut, but in this case probably the high temperature used, rather than the steam, is effective.

77. Technical Explanation of Humidity.—By humidity is commonly meant the moisture or dampness in the air. Ordinary air always contains more or less moisture; in fact, it is exceedingly difficult to obtain absolutely dry air. This moisture is usually present in the form of minute particles, producing an invisible vapor. When the moisture is visible, as a fog, the air is super-saturated and there are present droplets of free water which are not the same as vapor.

In order to understand the important relation of humidity to evaporation and the drying of lumber, a more detailed discussion follows.

Humidity is expressed in two ways—absolute and relative. By absolute humidity is meant the weight of water vapor in any given space, as so many grains per cubic foot, or so many grams per cubic meter.

By relative humidity is meant the ratio of the amount of water vapor or vapor pressure in the air to the maximum possible at *that temperature*. This is usually expressed in percentage. When the air contains all the moisture it can hold, it is said to be saturated, or has 100 per cent relative humidity; if it is half saturated, it is said to have a relative humidity of 50 per cent. For example, at 100°F. the air can hold a maximum of 20 grains¹ of moisture per cubic foot; but if only 15 grains are present per cubic foot, the relative humidity is 75 per cent.

Since the amount of moisture that the air can hold increases rapidly with the temperature (see again page 105 and Fig. 40), any increase in temperature lowers the relative humidity and any cooling of the air raises the relative humidity, provided the actual amount of moisture in the air remains practically uniform.

Figure 66 shows by means of curves how the relative humidity varies with the amount of moisture in the air and also with the temperature. The horizontal lines represent humidities from 0

¹ 437. 5 grains = 1 ounce (avoirdupois) = 28.3 grams.

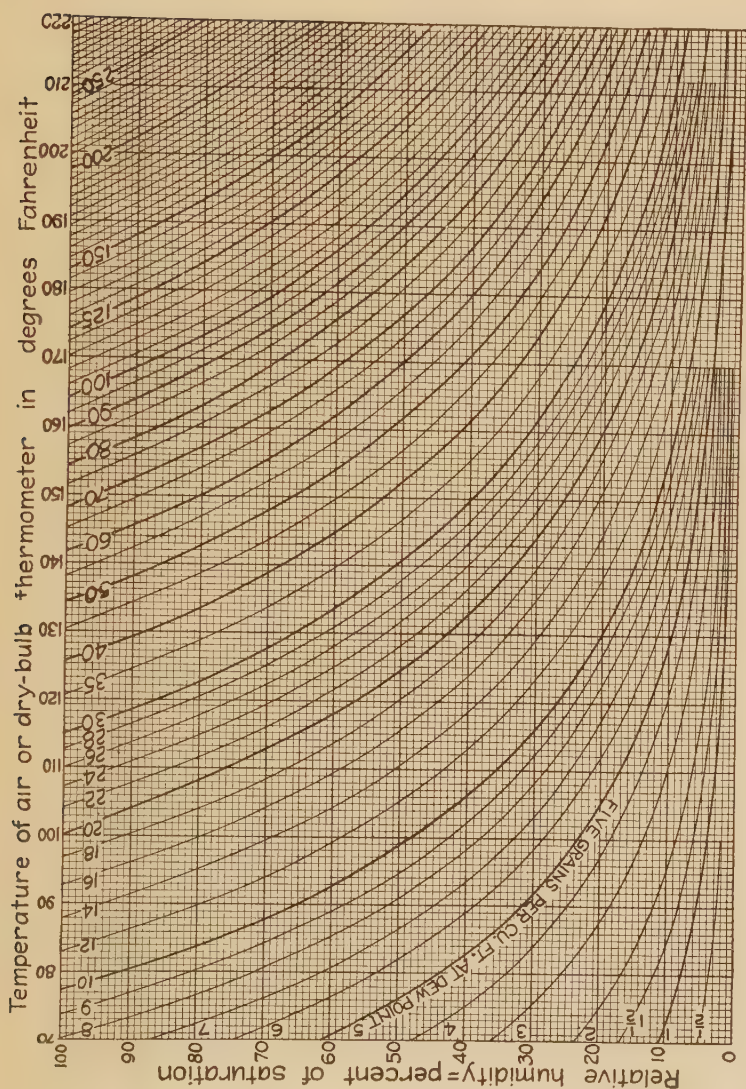


FIG. 66.—Chart for determining effect on relative humidity of raising or lowering temperature of air. (Reproduced from Forest Service Bull., #104, "Principle of Drying Lumber at Atmospheric Pressure, and Humidity Diagram.")

to 100 per cent; the vertical lines represent temperatures; and the curved lines represent the amount of moisture per cubic foot.¹ By following the curved lines from one temperature to another the effect on the relative humidity of heating and cooling air of a known relative humidity can be determined. For example, at 110°F. and 100 per cent relative humidity there are about 26 grains of moisture per cubic foot. If this air, containing 26 grains of vapor per cubic foot, is heated to 130°F., there will still be approximately the same amount of moisture per cubic foot of air, but the air will no longer be saturated, that is, the air will be able to hold more than 26 grains per cubic foot. By following the 26-grain line down to where it crosses the 130 vertical line it is found that the 57 horizontal line crosses it at the same point. This means that air saturated at 110°F., when heated to 130°F., has a humidity of only 57 per cent. Conversely, if air at 150°F. and 60 per cent humidity is cooled to 134°F., then its relative humidity will be raised to 90 per cent, as can be ascertained by following along the 45-grain line from the intersection of the 150° and 60 per cent lines to where it crosses the 134° line, and then noting what horizontal line crosses it at the same point.

The temperature to which air must be cooled to saturate it is known as the *dew point* of that air. For example, the dew point of air at 132°F. and 50 per cent humidity is 107°F. If air is cooled below the dew point, condensation takes place.

In these discussions the statement is often made that the air has a certain humidity. This is the common way of expressing it, but, in fact, the air has nothing to do with the relative or

¹ The figures indicating the number of grains of moisture per cubic foot hold only when the air is cooled to the dew-point temperature (saturation). The curved lines represent uniform vapor pressures instead of uniform vapor densities. The difference at other temperatures is not great, however. The concave lines are made to correspond to vapor pressures instead of to exact vapor densities, because a constant vapor pressure makes allowance for the expansion and the contraction which take place with changes in temperature, whereas a constant vapor density makes no such allowance; therefore, this chart can be followed from one temperature to another without error. For example, a cubic foot of air at 170°F. and 50 per cent humidity contains approximately 57 grains of moisture. If this is cooled, with the pressure remaining constant, it is no longer a cubic foot; and to make a cubic foot of the same relative amounts of air and water vapor, more air and moisture must be added. When cooled to 142°F. (dew point), the moisture so added amounts to 3 grains, making a total of 60 grains, while the vapor pressure has not changed.

absolute humidity. If from a certain volume of confined air with a humidity of 60 per cent it were possible, without changing its temperature, to pump out the air but not the water vapor, then the space without air would still have 60 per cent humidity. Or if in a tight vessel with or without air there were introduced a comparatively small amount of water, the water would evaporate until 100 per cent humidity was reached in the vessel. If air were present, the water-vapor pressure would add to the air pressure, increasing the total pressure. If the space were not confined, the water vapor would push the air aside, and no increase in pressure would take place. The amount of air so displaced depends upon the amount of water vapor present; that is, upon the temperature and the humidity. The rarefaction of the air at ordinary temperatures is not particularly noticeable even at

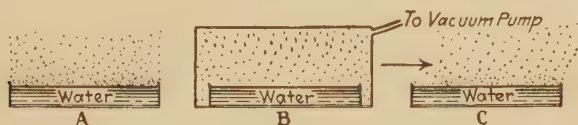


FIG. 67.—Differences in relative humidities near a wet surface and some distance from it. *A*, in still air; *B*, in a vacuum; *C*, in current of air blowing over surface.

100 per cent humidity, but the “stuffy” sensation experienced in entering a dry kiln with a high humidity, or even some greenhouses, is due partly to the relative scarcity of air. At 212°F. the pressure due to the water vapor is equal to the normal air pressure, as is indicated in Fig. 40. In the top of a boiling tea-kettle, for example, all the air is replaced by water vapor. Obviously, the force exerted by the water vapor cannot exceed the air pressure unless the vapor is confined.

The reader probably is ready to ask the question, “If the air has nothing to do with the humidity why will evaporation take place more rapidly in a vacuum?” The reason is this: If air is present, it interferes with the rapid diffusion of the water vapor and keeps a thin layer of much higher humidity at the very surface from which this liquid evaporates, and this higher humidity reduces the rate of evaporation. If air is absent, the particles of moisture do not remain long over the surface of the liquid, but fly off into space and, hence, evaporation takes place more rapidly. This fact is illustrated in Fig. 67.

78. Relation of Humidity to Evaporation.—The rate at which evaporation takes place from wet surfaces depends largely upon the relative humidity of the surrounding air. At a low humidity,

evaporation is rapid; at a high humidity, it is slow. The relative humidity alone, however, does not altogether determine the rate of drying. The temperature, the nature of the object from which the moisture is evaporated, the circulation of air, and the air pressure also influence the rate of evaporation. The first two of these factors will be taken up in this chapter; the effect of circulation on drying will be taken up in the next chapter. The air pressure may be assumed to be constant for most dry-kiln work, and its fluctuations need not be considered except in connection with superheated-steam kilns.

In order to understand the relation of humidity and temperature to the drying rate, it is necessary to discuss the principles of evaporation more fully. Water, as well as vapor, has a vapor pressure. This pressure increases rapidly with the temperature. The vapor pressure of a liquid causes minute particles to fly from its surface continuously. When the vapor pressure of the liquid is greater than that of the surrounding vapor, the liquid decreases in volume—"evaporates." When the vapor pressure of the surrounding medium is greater than that of the water (which can take place only when the water is cooler and the relative humidity of the air high), more moisture will condense on the surface of the water than evaporates, and it will increase in quantity. When the vapor pressure of the water is equal to that of the vapor in the surrounding air, as much condensation takes place as evaporation, and there is no net evaporation.¹

Wet wood acts in this respect like the surface of water; but as soon as the moisture content of the surface layers falls to below the fiber-saturation point, the vapor pressure of the contained moisture is reduced by the attraction of the wood for the water. Hence, partly dry wood is in equilibrium with the atmospheric humidity at less than 100 per cent relative humidity, as is shown in Fig. 11.

The rate of evaporation from moist wood is proportional, other things being equal, to the difference between the vapor pressure

¹ Evaporation may take place at 100 per cent humidity under two conditions: (1) If the object from which evaporation takes place is warmer than the surrounding air. This may take place in cooling a kiln charge of green lumber when the air in the kiln becomes cooler than the lumber. (2) If condensation on some other object takes place at the same rate as that of evaporation. For example, if the air in a kiln is saturated, vapor from the lumber may pass into the air as rapidly as the moisture condenses on the walls or condensers, thus keeping the air saturated.

of the water at the surface of the wood and that of the vapor in the surrounding air. This difference is known as the *saturation deficit*. For example, of two kilns each at 75 per cent humidity, one at a temperature of 125°F. and the other at 155°F., the latter will cause more rapid evaporation, other things being equal, because of a greater saturation deficit.

This point is exceedingly important, since in kilns run at higher temperatures than those given in schedules which give good results, the humidity must also be higher all through the run or serious casehardening and checking may result. It may not be necessary to raise the humidity enough to give the same saturation deficit as at lower temperatures, since at higher temperatures the moisture comes out of wood more easily and, therefore, a somewhat greater rate of surface drying can be maintained without injury. In ordinary kiln drying of lumber the saturation deficit is not considered because it is difficult to determine; and, because the temperature is fixed as high as is safe, the drying can be regulated by the relative humidity. The important thing to remember is—*the drying should not be regulated by temperature or humidity alone, the two go together*.

Of course, it is possible to run a kiln satisfactorily under certain conditions by maintaining a uniform temperature throughout the run and gradually lowering the humidity, or by maintaining a fixed relative humidity and raising the temperature as the drying progresses, but in either case the temperature and the humidity have a fixed relation. Usually the temperature is raised and the humidity lowered as the lumber dries. In any case, the humidity at any temperature should be such that the lumber will dry as rapidly as possible without the surface becoming very much drier than the interior, or checking, casehardening, and, later, honeycombing will result.

79. How the Relative Humidity Is Determined.—The relative humidity may be determined in a number of ways, but the most practical for dry-kiln work is by the use of what is known as the wet-and-dry-bulb hygrometer. This instrument consists of a stand on which are mounted two similar thermometers, except that the bulb of one is surrounded by a clean cotton or silk cloth or special wick which is kept wet by means of a small vessel of water into which it extends (see Fig. 68). If any evaporation takes place, the wet bulb will become cooled and the wet-bulb thermometer will show a lower temperature than the dry-

bulb thermometer. The drier the air the greater will be the evaporation, and the greater the "depression" or difference between the readings of the two thermometers. If the air is saturated, there will be no evaporation and the two thermometers will indicate the same temperature (provided they are accurate). The *difference* in the readings of the two thermometers alone does not give the relative humidity. The *dry-bulb temperatures*

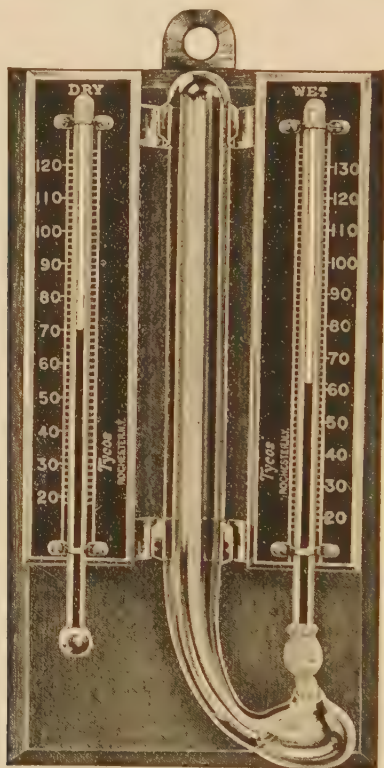


FIG. 68.—Wet- and dry-bulb hygrometer. (Courtesy, Taylor Instrument Co.)

must also be taken into account. From many careful experiments, tables have been worked out showing the relative humidities corresponding to differences in the readings of the wet- and the dry-bulb thermometers at various temperatures (see Table X). Thus, if the dry bulb indicates 130°F. and the wet bulb 120°F., the difference is 10°, which at 130°F. means a relative humidity of 73 per cent. If the dry bulb registers 180° and the

wet bulb 170° , the difference is also 10° , but at 180° this means a humidity of 79 per cent.

A recent improvement in hygrometry, developed at the Forest Products Laboratory, and now on the market, is a porous wet-bulb sleeve or receptacle which takes the place of the common wick. This receptacle is made of pottery, alundum, emery, or similar material and is porous enough to allow water to seep through it at a suitable rate. If it is kept filled with water and exposed to a current of air, the evaporation of the water from the outer surface of the walls will reduce the temperature of the

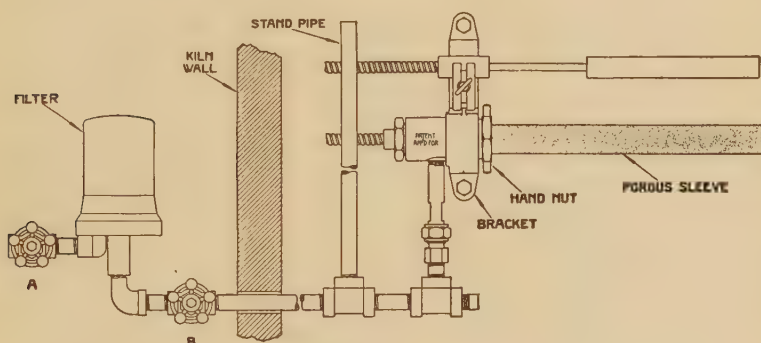


FIG. 69.—Porous wet-bulb sleeve. (Courtesy, Foxboro Co.)

This sleeve, which may be made of alundum or other porous material, completely surrounds the wet bulb and is filled with water under a slight pressure. The porosity of the sleeve is such that the water seeps slowly through the walls, to be evaporated on the outside surfaces. This evaporation reduces the sleeve and the bulb to the wet-bulb temperature. The action is precisely the same as that of the wet wick form of the wet-bulb thermometer.

receptacle and its contents to the wet-bulb temperature, and a thermometer the bulb of which is immersed in the water will indicate this temperature.

In a commercial application of this porous wet bulb to recorder regulators, illustrated in Fig. 69, the water is supplied to the receptacle under pressure, through a small tube running from the bulb to the water supply outside of the kiln.

TABLE X.—RELATIVE HUMIDITY TABLE FOR USE WITH WET- AND DRY-BULB THERMOMETERS

Difference between Wet-bulb and Dry-bulb Thermometers, in Degrees Fahrenheit

		1	2	3	4	5	6	7	8	9	10	11	12	13
Temperature of dry bulb	60	94	89	83	78	73	68	63	58	53	48	43	39	34
	70	95	90	86	81	77	72	68	64	59	55	51	48	44
	80	96	91	87	83	79	75	72	68	64	61	57	54	50
	90	96	92	89	85	81	78	74	71	68	65	61	58	55
	100	96	93	89	86	83	80	77	73	70	68	65	62	59
	102	96	93	90	86	83	80	77	74	71	68	65	62	60
	104	97	93	90	87	83	80	77	74	71	69	66	63	60
	106	97	93	90	87	84	81	78	75	72	69	66	64	61
	108	97	93	90	87	84	81	78	75	72	70	67	64	62
	110	97	93	90	87	84	81	78	75	73	70	67	65	62
	112	97	94	90	87	84	81	79	76	73	70	68	65	63
	114	97	94	91	88	85	82	79	76	74	71	68	66	63
	116	97	94	91	88	85	82	79	76	74	71	69	66	64
	118	97	94	91	88	85	82	79	77	74	72	69	67	64
	120	97	94	91	88	85	82	80	77	74	72	69	67	65
	122	97	94	91	88	85	83	80	77	75	72	70	67	65
	124	97	94	91	88	85	83	80	78	75	73	70	68	65
	126	97	94	91	88	86	83	80	78	75	73	70	68	66
	128	97	94	91	89	86	83	81	78	76	73	71	68	66
	130	97	94	91	89	86	83	81	78	76	73	71	69	67
	132	97	94	92	89	86	84	81	79	76	74	71	69	67
	134	97	94	92	89	86	84	81	79	76	74	72	69	67
	136	97	94	92	89	86	84	81	79	77	74	72	70	68
	138	97	94	92	89	87	84	82	79	77	75	72	70	68
	140	97	95	92	89	87	84	82	79	77	75	73	70	68
	142	97	95	92	89	87	84	82	80	77	75	73	70	68
	144	97	95	92	89	87	84	82	80	78	75	73	71	69
	146	97	95	92	90	87	85	82	80	78	75	73	71	69
	148	97	95	92	90	87	85	82	80	78	76	73	71	69
	150	98	95	92	90	87	85	82	80	78	76	74	72	70
	152	98	95	93	90	88	85	83	81	79	76	74	72	70
	154	98	95	93	90	88	85	83	81	79	77	74	72	70
	156	98	95	93	90	88	85	83	81	79	77	74	72	71
	158	98	95	93	90	88	86	83	81	79	77	75	73	71
	160	98	95	93	90	88	86	83	81	79	77	75	73	71
	162	98	95	93	90	88	86	84	82	80	77	75	73	71
	164	98	95	93	91	88	86	84	82	80	78	75	73	72
	166	98	95	93	91	88	86	84	82	80	78	76	74	72
	168	98	95	93	91	88	86	84	82	80	78	76	74	72
	170	98	95	93	91	89	86	84	82	80	78	76	74	72
	172	98	95	93	91	89	86	84	82	81	78	76	74	73
	174	98	95	93	91	89	87	84	83	81	78	76	75	73
	176	98	96	94	91	89	87	85	83	81	79	77	75	73
	178	98	96	94	91	89	87	85	83	81	79	77	75	73
	180	98	96	94	91	89	87	85	83	81	79	77	75	73
	182	98	96	94	91	89	87	85	83	81	79	77	75	74
	184	98	96	94	92	89	87	85	83	82	79	77	76	74
	186	98	96	94	92	90	87	85	83	82	80	78	76	74
	188	98	96	94	92	90	87	85	84	82	80	78	76	74
	190	98	96	94	92	90	88	85	84	82	80	78	76	75
	200	98	96	94	92	90	88	86	84	82	80	79	77	75
	210	98	96	94	92	90	88	86	85	83	81	79	78	76
	220	98 ^a	96 ^a	94 ^a	92 ^a	91 ^a	89 ^a	87 ^a	85 ^b	83	82	80	78	77

^a Possible only at pressures higher than normal atmosphere.^b Superheated steam, at normal atmospheric pressure, no air present. At lower humidities air is mixed with the water vapor.

TABLE X.—RELATIVE HUMIDITY TABLE FOR USE WITH WET- AND DRY-BULB THERMOMETERS.—*Continued*

Difference between Wet-bulb and Dry-bulb Thermometers, in Degrees Fahrenheit

		14	15	16	17	18	19	20	21	22	23	24	25	26
Temperature of dry bulb	60	30	26	21	17	13	9	5	1					
	70	40	36	33	29	25	22	19	15	12	9	6	3	
	80	47	44	41	38	35	32	29	26	23	20	18	15	12
	90	52	49	47	44	41	39	36	34	31	29	26	24	22
	100	56	54	51	49	46	44	41	39	37	35	33	30	28
	102	57	55	52	49	47	45	42	40	38	36	34	32	30
	104	58	55	53	50	48	46	43	41	39	37	35	33	31
	106	58	56	53	51	49	46	44	42	40	38	36	34	32
	108	59	57	54	52	49	47	45	43	41	39	37	35	33
	110	60	57	55	52	50	48	46	44	42	40	38	36	34
	112	60	58	55	53	51	49	47	44	42	40	38	36	35
	114	61	58	56	54	52	49	47	45	43	41	39	37	35
	116	61	59	57	54	52	50	48	46	44	42	40	38	36
	118	62	59	57	55	53	51	49	47	45	43	41	39	37
	120	62	60	58	55	53	51	49	47	45	43	41	40	38
	122	63	60	58	56	54	52	50	48	46	44	42	40	39
	124	63	61	59	57	54	52	50	48	47	45	43	41	39
	126	64	61	59	57	55	53	51	49	47	45	44	42	40
	128	64	62	60	58	56	54	52	50	48	46	44	42	41
	130	64	62	60	58	56	54	52	50	48	47	45	43	41
	132	65	63	61	58	56	55	53	51	49	47	45	44	42
	134	65	63	61	59	57	55	53	51	49	48	46	44	43
	136	65	63	61	59	57	55	54	52	50	48	46	45	43
	138	66	64	62	60	58	56	54	52	50	49	47	45	44
	140	66	64	62	60	58	56	54	53	51	49	47	46	44
	142	66	64	62	60	58	57	55	53	51	49	48	46	44
	144	67	65	63	61	59	57	55	53	52	50	48	47	45
	146	67	65	63	61	59	57	56	54	52	50	49	47	45
	148	67	65	63	61	60	58	56	54	52	51	49	48	46
	150	68	66	64	62	60	58	57	55	53	51	49	48	46
	152	68	66	64	62	60	59	57	55	53	52	50	48	47
	154	68	66	65	63	61	59	57	56	54	52	50	49	47
	156	69	67	65	63	61	59	58	56	54	53	51	49	48
	158	69	67	65	63	61	60	58	56	55	53	51	50	48
	160	69	67	65	64	62	60	58	57	55	53	52	50	49
	162	69	68	66	64	62	60	59	57	55	54	52	51	49
	164	70	68	66	64	62	61	59	58	56	54	52	51	49
	166	70	68	66	65	63	61	59	58	56	54	53	51	50
	168	70	68	67	65	63	61	60	58	56	55	53	52	50
	170	70	69	67	65	63	62	60	59	57	55	53	52	51
	172	71	69	67	66	64	62	60	59	57	55	54	53	51
	174	71	69	67	66	64	62	61	59	57	56	54	53	51
	176	71	70	68	66	64	63	61	60	58	56	55	53	52
	178	72	70	68	66	64	63	61	60	58	56	55	54	52
	180	72	70	68	67	65	63	62	60	58	57	55	54	52
	182	72	70	68	67	65	63	62	60	59	57	56	54	53
	184	72	70	69	67	65	64	62	61	59	57	56	55	53
	186	72	71	69	67	66	64	62	61	59	58	56	55	53
	188	73	71	69	68	66	64	63	62	59	58	57	55	54
	190	73	71	69	68	66	65	63	62	60	58	57	56	54
	200	74	72	70	69	67	66	64	63	61	60	58	57	55
	210	75	73	71	70	68	67	65	64	63	61	60	59	57
	220	75	74	72	71	69	68	66	65	64	62	61	60	58

TABLE X.—RELATIVE HUMIDITY TABLE FOR USE WITH WET- AND DRY-BULB THERMOMETERS.—*Continued*

Difference between Wet-bulb and Dry-bulb Thermometers, in Degrees Fahrenheit

		27	28	29	30	31	32	33	34	35	36	37	38
Temperature of dry bulb	60												
	70												
	80	10	7	5	3								
	90	19	17	15	13	11							
	100	26	24	22	21	19	17	15	13	12	10	8	7
	102	28	26	24	22	20	18	16	15	13	11	10	8
	104	29	27	25	23	21	20	18	16	14	13	11	10
	106	30	28	26	24	23	21	19	17	16	14	13	11
	108	31	29	27	25	24	22	20	19	17	16	14	12
	110	32	30	28	26	25	23	21	20	18	17	15	14
	112	33	31	29	27	26	24	23	21	19	18	16	15
	114	34	32	30	28	27	25	24	22	20	19	18	16
	116	34	33	31	29	28	26	25	23	22	20	19	17
	118	35	34	32	30	29	27	25	24	23	21	20	18
	120	36	34	33	31	29	28	26	25	23	22	21	19
	122	37	35	34	32	30	29	27	26	24	23	22	20
	124	38	36	34	33	31	30	28	27	25	24	22	21
	126	38	37	35	33	32	30	29	27	26	25	23	22
	128	39	37	36	34	33	31	30	28	27	25	24	23
	130	40	38	37	35	33	32	30	29	28	26	25	24
	132	40	39	37	36	34	33	31	30	28	27	26	24
	134	41	39	38	36	35	33	32	30	29	28	26	25
	136	41	40	38	37	35	34	33	31	30	28	27	26
	138	42	40	39	37	36	35	33	32	30	29	28	27
	140	43	41	40	38	37	35	34	32	31	30	29	27
	142	43	42	40	39	37	36	34	33	32	30	29	28
	144	44	42	41	39	38	36	35	34	32	31	30	29
	146	44	43	41	40	38	37	36	35	33	32	30	29
	148	45	43	42	40	39	38	36	35	34	32	31	30
	150	45	43	42	41	39	38	37	36	34	33	31	30
	152	46	44	42	41	40	39	37	36	35	33	32	31
	154	46	44	43	42	40	39	38	37	35	34	33	32
	156	46	45	43	42	41	40	38	37	36	34	33	32
	158	47	45	44	43	41	40	39	38	36	35	34	33
	160	47	46	44	43	42	41	39	38	37	35	34	33
	162	47	46	45	44	42	41	40	39	37	36	35	34
	164	48	47	45	44	43	41	40	39	38	36	35	34
	166	48	47	45	44	43	42	41	39	38	37	36	35
	168	49	47	46	45	43	42	41	40	39	37	36	35
	170	49	48	47	45	44	43	41	40	39	38	37	35
	172	50	48	47	46	45	43	42	41	39	38	37	36
	174	50	49	47	46	45	43	42	41	40	39	37	36
	176	50	49	48	46	45	44	43	42	40	39	38	37
	178	51	49	48	47	46	44	43	42	41	39	38	37
	180	51	50	48	47	46	45	43	42	41	40	39	38
	182	51	50	49	48	46	45	44	43	42	40	39	38
	184	52	50	49	48	47	45	44	43	42	41	39	38
	186	52	51	49	48	47	46	44	43	42	41	40	39
	188	52	51	50	49	47	46	45	44	43	41	40	39
	190	53	51	50	49	48	46	45	44	43	42	41	39
	200	54	53	42	51	49	48	47	46	45	43	42	41
	210	56	54	53	52	51	50	48	47	46	45	44	43
	220	57	56	54	53	52	51	50	48	47	46	45	44

TABLE X.—RELATIVE HUMIDITY TABLE FOR USE WITH WET- AND DRY-BULB THERMOMETERS.—*Continued*

Difference between Wet-bulb and Dry-bulb Thermometers, in Degrees Fahrenheit

		39	40	41	42	43	44	45	46	47	48	49	50
Temperature of dry bulb	60												
	70												
	80												
	90												
	100	5	4	2	1								
	102	7	5	4	2	1							
	104	8	7	5	4	2	1						
	106	10	8	7	5	4	3	1					
	108	11	10	8	7	5	4	3	2				
	110	12	11	10	8	7	6	4	3	2	1		
	112	14	12	11	9	8	7	6	4	3	2	1	
	114	15	13	12	11	9	8	7	6	5	3	2	1
	116	16	14	13	12	11	9	8	7	6	5	4	2
	118	17	16	14	13	12	11	9	8	7	6	5	4
	120	18	17	15	14	13	12	10	9	8	7	6	5
	122	19	18	16	15	14	13	11	10	9	8	7	6
	124	20	18	17	16	15	14	12	11	10	9	8	7
	126	21	19	18	17	16	15	13	12	11	10	9	8
	128	22	20	19	18	17	16	14	13	12	11	10	9
	130	22	21	20	19	18	16	15	14	13	12	11	10
	132	23	22	21	20	18	17	16	15	14	13	12	11
	134	24	23	21	20	19	18	17	16	15	14	13	12
	136	25	23	22	21	20	19	18	17	16	15	14	13
	138	25	24	23	22	21	20	19	17	16	15	14	14
	140	26	25	24	23	21	20	19	18	17	16	15	14
	142	27	26	24	23	22	21	20	19	18	17	16	15
	144	27	26	25	24	23	22	21	20	19	18	17	16
	146	28	27	26	25	24	22	21	20	19	18	17	17
	148	29	28	26	25	24	23	22	21	20	19	18	17
	150	29	28	27	26	25	24	23	22	21	20	19	18
	152	30	29	28	26	25	24	23	22	21	20	19	19
	154	30	29	28	27	26	25	24	23	22	21	20	19
	156	31	30	29	28	27	25	24	23	23	22	21	20
	158	31	30	29	28	27	26	25	24	23	22	21	20
	160	32	31	30	29	28	27	25	24	24	23	22	21
	162	32	31	30	29	28	27	26	25	24	23	22	22
	164	33	32	31	30	29	28	26	25	25	24	23	22
	166	33	32	31	30	29	28	27	26	25	24	23	23
	168	34	33	32	31	30	29	28	27	26	25	24	23
	170	34	33	32	31	30	29	28	27	26	25	24	24
	172	35	34	33	32	31	30	28	27	26	26	25	24
	174	35	34	33	32	31	30	29	28	27	26	25	24
	176	36	35	34	33	32	31	29	28	27	27	26	25
	178	36	35	34	33	32	31	30	29	28	27	26	25
	180	36	35	35	34	33	31	30	29	28	27	27	26
	182	37	36	35	34	33	32	31	30	29	28	27	26
	184	37	36	35	34	33	32	31	30	29	28	27	27
	186	38	37	36	35	34	33	32	30	30	29	28	27
	188	38	37	36	35	34	33	32	31	30	29	28	27
	190	38	37	36	35	34	33	32	31	30	30	29	28
	200	40	39	38	37	36	35	34	33	32	32	31	30
	210	42	41	40	39	38	37	36	35	34	33	32	32
	220	43	42	41	41	39	39	38	37	36	35	34	33

In reading the wet-bulb thermometer, care should be taken to have a good circulation of air around it so as to produce a maximum evaporation at that humidity, since the tables are based on this condition. If the air is not circulating freely around the bulb, sufficient movement may be produced by fanning it with a suitable object. A circulation of at least 5 feet per second past the wet bulb is necessary to secure correct humidity determinations at ordinary temperatures; but if the temperature in the kiln is above 125°F., it is not necessary to pay any particular attention to the circulation around the wet bulb.

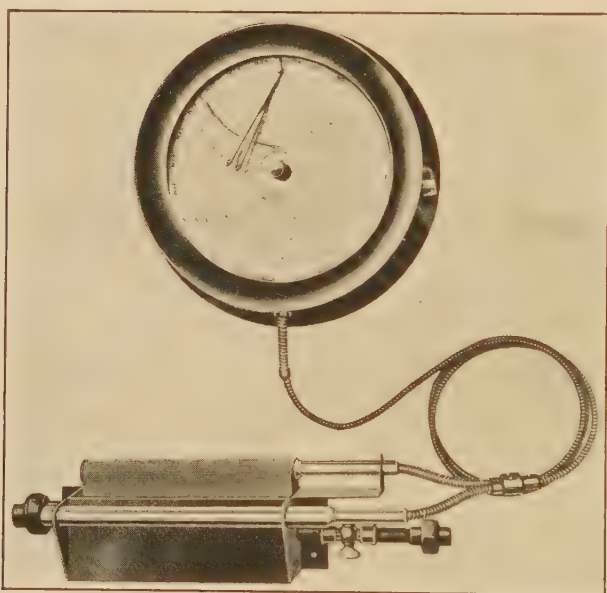


FIG. 70.—Wet and dry-bulb recording hygrometer. (Courtesy, Brown Instrument Co.)

Only distilled water or clean rain water should be used to moisten the wicks; even then they become clogged so that it is necessary to change them once every week or two. Where it is necessary to use hard water, the wicks must be changed more frequently. Wicks should not be touched with greasy fingers, or the proper flow of water through them will not be secured.

A so-called recording hygrometer is manufactured which consists of two recording thermometer bulbs recording on the same dial. One bulb is surrounded by a piece of cloth kept moist

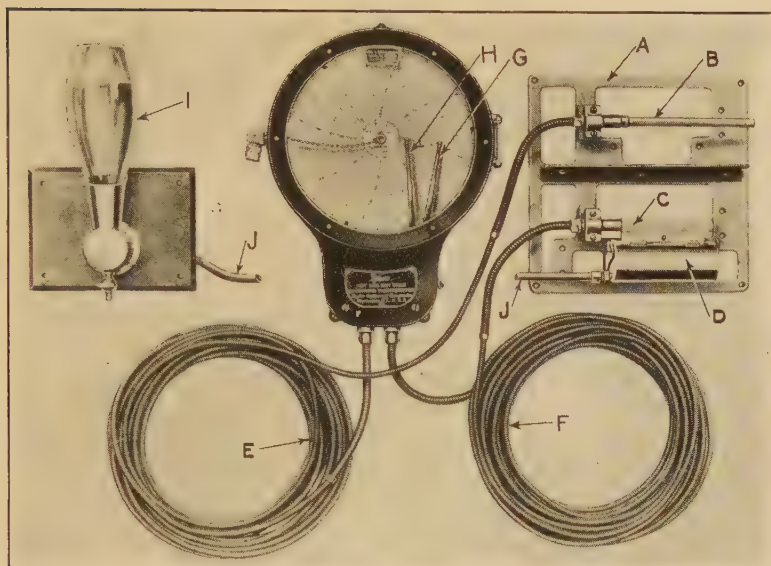


FIG. 71.—A double-pen recording thermometer with wet and dry bulbs. (Courtesy, Taylor Instrument Co.)

The frame *A*, with the two bulbs *B* and *C*, and the reservoir *D*, is placed in the kiln, the extension tubes *E* and *F* connecting the bulbs with the instrument. The wet bulb *C* is covered with a wick which dips into the water trough *D*, and keeps itself and the bulb wet by capillarity. The bottle *I* and the connecting tube *J* serve to maintain a constant level of water in the trough. Pen *G* records the kiln temperature and *H* the wet bulb temperature. From these two the relative humidity can be calculated.

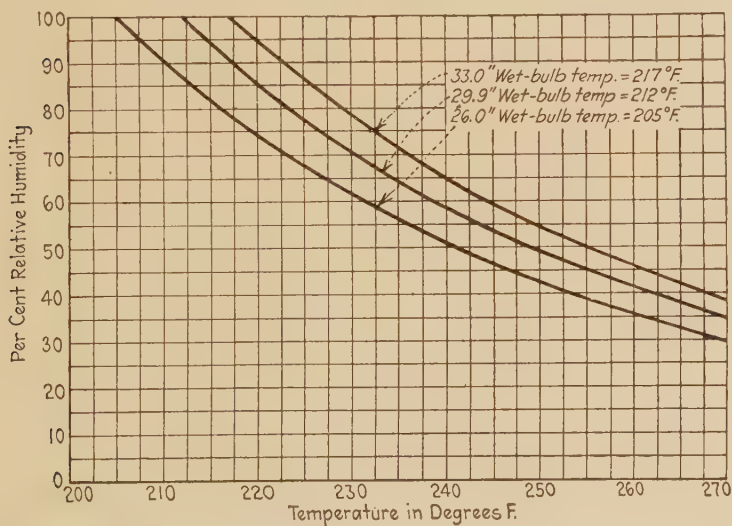


FIG. 72.—Relative humidity curves for superheated steam at three different atmospheric pressures.

by means of a trough of water into which it extends. Recorders of this type are illustrated in Figs. 70 and 71. On account of the inaccuracy of many recording thermometers, too much reliance must not be placed on a recording hygrometer, since a difference of a few degrees more or less would make considerable difference in the determination of the humidity.

In a superheated-steam kiln the wet-bulb thermometer may be dispensed with, since it will not record temperatures higher than the boiling point of water, which is 212°F. at normal atmospheric pressure. From the temperature of the dry bulb and the barometric pressure, the relative humidity can be determined as indicated in Fig. 72, provided all the air is replaced by steam. If a wet-bulb thermometer is used and it shows a temperature below the boiling point corresponding to the atmospheric pressure, the steam cannot be said to be superheated. Table XI gives the relative humidities of superheated steam at various temperatures when the boiling point of water is 212°F.

TABLE XI.—RELATIVE HUMIDITIES OF SUPERHEATED STEAM AT NORMAL ATMOSPHERIC PRESSURE

Temperature, degrees Fahrenheit	Relative humidity, per cent	Temperature, degrees Fahrenheit	Relative humidity, per cent
212	100	238	60.9
214	96.2	240	58.7
216	92.5	242	56.6
218	89.0	244	54.5
220	85.6	246	52.6
222	82.3	248	50.8
224	79.1	250	49.1
226	76.1	252	47.4
228	73.3	254	45.8
230	70.6	256	44.3
232	68.1	258	42.8
234	65.6	260	41.4
236	63.2		

80. How Humidity Is Supplied and Regulated.—At first thought, the big problem in humidity regulation would seem to be to get rid of the moisture evaporated from the lumber, and

most of the early kilns were designed with this thought uppermost in mind. Although it may seem strange, the problem is usually to keep up the humidity by the addition of moisture from outside sources rather than to reduce it. The regulation of humidity is intimately associated with the circulation of air and the means for producing it. In ventilated kilns, in which fresh air is taken from outside of the kiln and moisture-laden air is discharged from the kiln, usually through flues, it is almost necessary to add moisture to the air. In recirculating kilns, without outside air connections, the amount of natural leakage from the kiln governs in large measure the need for adding moisture. If the kiln is very tight, it is sometimes possible to keep up the desired humidity without adding any moisture to the air. Since the kiln is always hotter than the surrounding atmosphere, the air inside is lighter than the outside and there is a slight difference in pressure, just as there is between the hot air in a chimney and the cooler air outside. This results in a continual leakage of cold air into the kiln at the bottom and of hot air out of the kiln at the top. This leakage tends to reduce the humidity of the air in the kiln because the cold air contains less moisture than the air in the kiln. This leakage can be observed readily by blowing smoke into the crevices at the bottom of the door, or by watching the leakage of vapor on a cold morning or when the steam jets are on in the kiln. A shimmering of the air immediately above the doors can also often be noticed. This shimmering is similar to that observed on very hot days, and is caused by hot air leaking out between the door and the door frame.

To provide for all the conditions to be encountered, it is, in most cases, desirable to supply means for both reducing and increasing the humidity. Humidity may be reduced (1) by removing some of the moisture from the kiln atmosphere, and (2) by removing some of the moist air in the kiln and replacing it with drier air, thus reducing the humidity of the mixture. Both methods are in common use and are well adapted to dry-kiln needs. Condenser kilns use method (1). In pipe condenser kilns, cold water is circulated through coils of pipe usually mounted on the side walls of the kiln, and the air coming in contact with the cold pipes is cooled below its dew point, some of its moisture being condensed out as a result. This moisture is usually caught in a trough and allowed to drain out of the kiln.

In the water-spray condenser kiln, the air is passed through a fine spray of cold water and is cooled to the dew point called for by the drying schedule. It then leaves the spray chamber saturated at that temperature, irrespective of the amount of moisture it may have held previously. If it was too moist, some of the water was condensed out in the sprays, and if too dry, some was added to it from the sprays. The water sprays thus regulate and adjust the dew point of the air to the desired degree. The air passes from the spray chamber to the heating coils and is heated to the proper temperature before it enters the lumber pile again. This process of saturating the air at the proper temperature and then heating it up to another temperature automatically produces a definite and unchanging humidity at the latter temperature.

The curtain kiln employs a modification of the condenser principle to reduce the humidity. The side walls of the drying chamber are made of canvas, the outer surface of which is exposed to a ventilating current of outside air which cools the canvas and thus makes it perform the duties of a condenser. The moisture removed from the kiln atmosphere by the canvas transpires through it and is carried away on the ventilating air current. Figure 35 is a diagrammatic drawing of this kiln.

Ventilated kilns and most recirculating kilns with blowers, except the curtain kiln, use method (2). In the natural-draught ventilated kilns inlet ducts are usually provided near the bottom of the kiln, and exhaust ducts or chimneys arranged to discharge above the kiln roof. The air thus drawn in and discharged serves to produce a certain amount of circulation in the kiln, besides reducing the humidity. In blower kilns using a centrifugal blower, cold air from the outside atmosphere can be introduced into the system most easily through a slide damper located on the suction side of the blower. Opening this allows the blower to draw in air from the fan room. This displaces an equivalent amount of kiln air, which is forced out through leaks or through vents in the roof. In blower kilns of the internal-fan type, the desired dilution of the air in the kiln may be obtained by vents located in almost any convenient manner, either at the bottom of the kiln or at the top, or both. It is remarkable how easy it is to "lose humidity."

Humidity is almost invariably "kept up" or increased by means of jets or sprays of steam, either live or exhaust, when it is not possible to keep it up by shutting off the means provided

for reducing it. Exception must, of course, be made of the water-spray kilns, since the water sprays automatically increase or decrease the humidity as becomes necessary. There are various other ways in which the humidity of the air may be increased, but they are of no interest to the kiln operator. The steam jets or sprays can be made to assist the air circulation in the kiln as well as to add humidity; their design and arrangement will in large measure determine their efficiency in this regard. The use of live steam is recommended in most cases, because it is more efficient than exhaust steam as a producer of circulation, and it will quickly raise the humidity and temperature for short steaming periods. From the standpoint of simple humidity increase, the manner of introducing the steam is not of such paramount importance, and for this reason the arrangement of jets and sprays is discussed under Circulation.

81. Control of Humidity.—Control of humidity may be manual or automatic, or a combination of both. Except in the water-spray kiln, in which the humidity is absolutely controlled by controlling the temperature of the spray water and that of the kiln, the reduction of the humidity is almost invariably accomplished by hand regulation; that is, by the manipulation of the dampers on the air intakes and vents, or the valves on the condensers. Hand control of the steam sprays may be combined with hand control of the dampers, the desired change being accomplished by the proper adjustment of one or both. If the control of the steam sprays is automatic, however, it is customary to set the dampers wide enough to insure a humidity which will be at all times lower than that desired. The automatic control on the steam sprays will then add enough moisture to keep the humidity up to the proper point. This method of reducing the humidity below the desired point is necessary because the automatic control can only *add* moisture and can, consequently, not act to *reduce* the humidity.

Manual control of humidity is accomplished by a hand valve on the steam-spray line, sometimes coupled with a reducing valve. A reducing valve permits somewhat closer regulation, since it provides a uniform pressure and also allows the hand valve to be wider open. This arrangement facilitates ease of adjustment and reduces the wear on the valve and the seat, resulting from wire drawing through a valve slightly open. Full boiler pressure should be available for steaming treatments.

Various physical principles are used in the design of instruments for the control of humidity in different industries and for various purposes. Three classes of instruments may be considered of commercial importance, as follows:

1. Those using hair as the "humidity-sensitive" element.
2. Those in which the swelling and the shrinking of a block of wood with changing humidity operate the control mechanism.
3. Wet-bulb instruments.

The third class is the only one commercially used in dry kilns. These instruments operate on the same principle as the wet-and-dry-bulb hygrometer; namely, that a wet substance exposed to a current of air is cooled, by the evaporation of moisture from its surface, an amount depending upon the humidity of the air. This cooling, or "wet-bulb depression," is a fixed quantity for any given air temperature and humidity if a sufficient air current is present.

There are two ways in which the "wet-bulb" principle is customarily employed: (1) one in which a "wet-bulb" thermostat is used to keep the "wet-bulb" *temperature* constant, other means being provided for keeping the sensible temperature (the "dry-bulb" temperature, or the temperature of the kiln) constant; and (2) one in which a "differential" instrument is used. The latter keeps the wet-bulb depression fairly uniform, resulting in a reasonably constant relative humidity regardless of small variations in the kiln temperature. With this instrument also, it is necessary to provide other means for regulating the kiln temperature.

It is obvious that the humidity can be kept constant with a wet-bulb thermostat only if the kiln temperature is regulated accurately. If the thermostat on the heating coils fails to operate properly, and the kiln temperature rises, the humidity will fall, even if the wet-bulb thermostat operates perfectly. Likewise, if the kiln temperature falls, the humidity will rise. The differential instrument has been designed to overcome this defect.

Controllers for regulating the wet-bulb temperature do not differ from the dry-bulb thermostats used for regulating the kiln temperature; in fact, the same instruments are used interchangeably for both purposes. The temperature-sensitive element (the bulb or the expansion bars) must, of course, be provided with a wet wick and exposed to a reasonable air circula-

tion. The wick is kept wet by means of a reservoir in which the water level is automatically maintained at the proper height. Several methods are used for this purpose: (1) The reservoir may be equipped with a float valve; (2) an overflow arrangement with

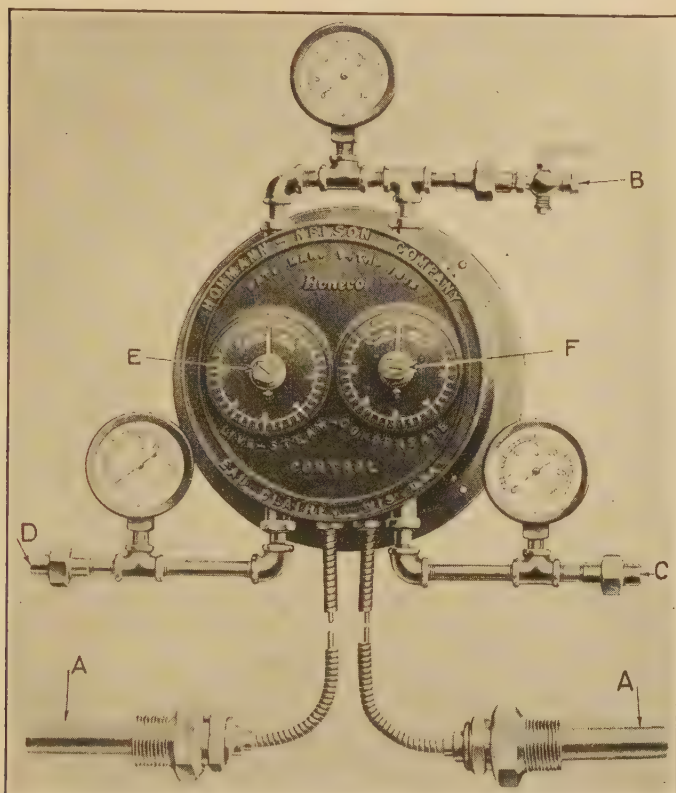


FIG. 73.—A double air-operated thermostat. (Courtesy, American Schaeffer and Budenberg Co.)

Regulators of this type are used for the control of the temperature and the humidity in dry kilns. One of the bulbs *A* is used as a dry bulb, controlling the kiln temperature, and the other one as a wet bulb, controlling the wet bulb temperature. The two in conjunction thus control both temperature and humidity. The air supply is connected to *B*, and the diaphragm valves to *C* and *D* respectively. The instrument is set for the desired temperature by turning the posts *E* and *F*. This instrument operates on the same principle as the single duty instruments described and illustrated in Chapter VI. When the regulator is used in a dry kiln, the union connections on the bulbs are not needed.

a continuous flow of water may be used; or (3) an inverted bottle dipping into a water cup may be made to serve the purpose. All three methods will give good service if clean water is available and if the apparatus is carefully watched. All wet-bulb instru-

ments need frequent inspection, and the wicks must be replaced often, especially if hard water is used.

To insure reasonably good control of the humidity it is necessary that both wet- and dry-bulb thermostats be sensitive and

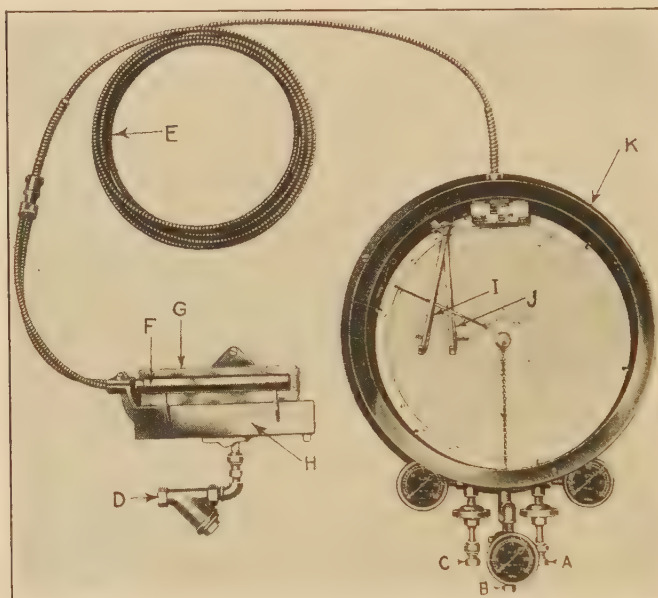


FIG. 74.—A double-pen, air-operated recorder regulator. (Courtesy, Foxboro Co.)

This instrument is arranged to control both the dry bulb and the wet bulb temperatures and to record them as well. As ordinarily constructed, it is adapted to reverse-acting diaphragm valves and an air pressure of about 15 pounds per square inch. Each bulb, extension tube, and helical spring capsule is made to serve a double purpose, in that the movement of the helical spring capsule actuates both the pen arm and the finger which controls the air valve. Air is supplied at *B* and delivered to the diaphragm valves from *A* and *C*. Water under pressure enters the water trough *H* at *D*, passing through a filter first. The level of the water is maintained by means of a float and needle valve. *F* and *G* are the dry and wet bulbs, respectively. The extension tubes are both incased in a single armored cable *E*, and enter the case *K* at the top. The operation of the air valves is not accomplished direct as in most air-operated thermostats, but by means of a small metal bellows on each. This bellows derives its power from the air pressure; its action is controlled by a small air leak. When this leak is open, the bellows is collapsed by the spring of the metal of which it is made; but when this leak is closed or stopped, air pressure builds up in the bellows, expanding it and thus operating the air valve. This leak is opened and closed by a finger linked to the pen arm and moving with it. The adjustment or setting of the instrument is accomplished by moving the adjusting arms *I* and *J*, which are directly under the pen arms, to the desired temperature on the chart. If the instrument is functioning properly, the temperature of each bulb, as indicated by its respective pen arm, will be that shown on the chart by the adjusting arms, and the pen arms will ride directly over the adjusting arms.

positive in action. For this reason air-operated instruments should be used rather than those of the self-contained type. It is sometimes more convenient, when it is desired to regulate both wet- and dry-bulb temperatures, to install duplex instru-

ments, which are simply two thermostats in a single case, rather than to use two separate instruments. A double air-operated temperature regulator is illustrated in Fig. 73. The operating efficiency is the same in either case. Combined, air-operated recorders and regulators of the double type are illustrated in Figs. 74 and 76.

82. Oscillating-treatment Controllers.—Several types of humidity controllers, designed to produce periodic variations in the humidity in the kiln, have recently appeared on the market. These periodic variations, or intermittent high-humidity treatments, are intended to hasten the drying and to reduce the amount of drying stresses. Present indications are that oscillating drying schedules show faster drying in some types of ventilated kilns, but that little increase in the drying rate may be expected in forced-circulation kilns. There are several principles on which these controllers may be constructed, and there are one or two types of controllers now used in other industries which can be adapted to this kind of service. All the oscillating-treatment controllers now on the market are intended to control the humidity so that it is not kept constant at any one point for an appreciable length of time—it must always be either rising or falling.

These controllers all use steam for humidification and depend upon outside forces for dehumidification (mostly ventilation and leakage).

Controllers producing the results just described may be divided into several classes:

1. Self-contained, differential.
2. Air-operated.
3. Electrically operated.
4. Fluid-pressure and electrically operated.

(a) *Self-contained Type.*—The self-contained differential type employs a wet-bulb system and a dry-bulb system, the diaphragm motors of the two systems working in opposition to each other. A lever with a sliding weight is linked to these motors and to the steam-spray valve in such a way that when the humidity drops to the desired low point the weight slides out on the lever (the steam valve opening at the same time) and holds the valve open until the humidity has risen to the desired high point. The increased pressure in the wet-bulb system then lifts up the lever, the weight slides in, and the steam valve shuts, remaining shut until the desired low humidity is again reached.

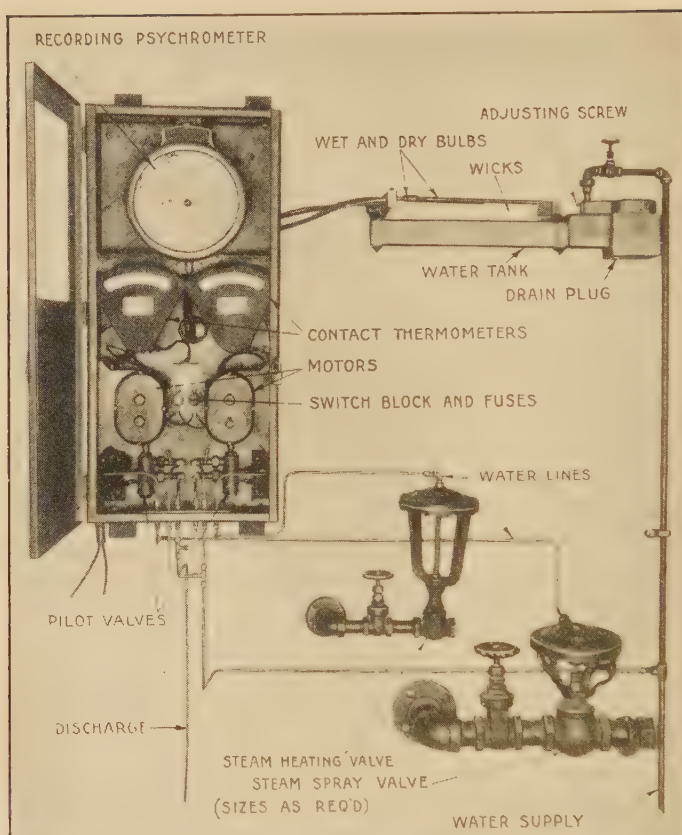


FIG. 75.—The moistat, model 5. (Courtesy, National Dry Kiln Co.)

This, the latest model moistat, is an oscillating-treatment controller of the auxiliary-operated type using electricity and water under pressure as the operating medium (air or oil under pressure may be used in place of water). The recording psychrometer shown in the illustration is not part of the control system but is an entirely separate instrument which indicates and records the wet-bulb and dry-bulb temperatures in the kiln. The moistat controls both dry-bulb and wet-bulb temperatures by means of two control systems which are virtually duplicates of each other except for the wet wick and water tank on the wet-bulb controller. Each system is composed of several units and their connections, namely, a contact thermometer, an electric motor, a pilot valve, and a steam valve. The contact thermometer has an extension tube and bulb and a helical pressure-sensitive element to which a pointer is linked. The extension tube and bulb are shown in the figure; the helical pressure-sensitive element is similar to the one illustrated in Fig. 58. A scale indicating temperature is mounted back of the pointer, and two adjustable electrical contacts are so arranged, one on the low-temperature side of the pointer and the other on the high-temperature side, that the pointer can make contact with each of them at any desired temperature and so that the temperature range between them may be of any desired size. These contacts complete electrical circuits which operate the electric motor, which in turn operates the pilot valve controlling the flow of water to and from the diaphragm motor of the steam valve. When the low contact is made, the electric motor sets the pilot valve to release the pressure in the diaphragm motor, allowing the steam valve to open. It remains open until the high contact is made, when the electric motor sets the pilot valve to admit pressure to the diaphragm motor, thus shutting off the steam. This cycle of operations is repeated indefinitely during the operation of the kiln. In the case of the system controlling the heating valve, the high and low contacts are usually set quite close together, so that the temperature fluctuations may be comparatively small; with the spray system, however, the contacts are usually set quite far apart—in some cases as much as 15 degrees—so as to produce the desired alternations or oscillations in humidity.

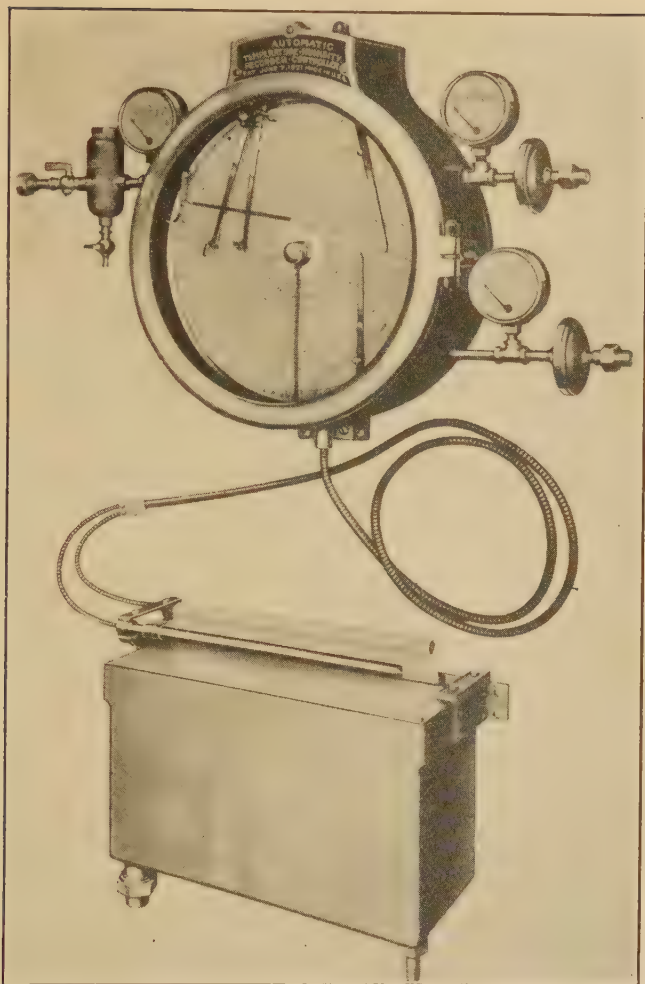


FIG. 76.—A double-pen air-operated recorder regulator. (Courtesy, C. J. Tagliabue Mfg. Co.)

This instrument performs substantially the same function as the one illustrated in Fig. 74. There are, however, several points of difference in the instruments themselves. This one uses direct-acting diaphragm valves (in which the air pressure *closes* the valve); the linkage of the pen arms is so arranged that the scale divisions on the chart are uniform in size, even though the instrument is of the vapor-filled type. The setting pointers are opposite the pen arms, instead of directly underneath them as in several other makes. All of the various makes can be supplied with single or double extension tubes of almost any desired length, and with either porous sleeve or wick type of wet bulb.

Adjustment of the stops on the weight determines the high and low humidities.

(b) *Air-operated Type*.—In the air-operated type a small bellows with an air leak is used to operate the air valve which controls the air supply to the diaphragm valve on the steam-spray line. The finger which opens and closes the air leak is operated by a mechanical device with a variable amount of play in it. The amount of this play determines the range in wet-bulb temperature. The usual wet bulb, extension tube, and helical spring are used.

(c) *Electrically Operated Type*.—A contact arm, which is controlled by a wet bulb, extension tube, and spring capsule or helical-spring movement of the usual type, operates between two adjustable contact points in the electrically operated oscillating controller. When it makes electrical contact with the lower one of these points, electric current operates to open a valve on the steam-spray line; and when contact is made with the upper one, the steam-spray valve is closed. The location of the contact points determines the upper and lower limits of the wet-bulb temperature. The precise system of controlling the steam valve may vary considerably. For very small valves a solenoid valve in direct circuit with the controller might be used. For larger valves a relay should be interposed, or motor-operated valves should be used.

(d) *Fluid-pressure and Electrically Operated Type*.—The controller elements in this type may be quite similar to those in the electrically operated type. The electric current operates a small electric motor which in turn operates a pilot valve controlling the fluid pressure in the diaphragm motor of the steam valve. The fluid may be oil, air, or water. Figure 75 illustrates the model 5 moistat, which is an instrument of this type. It controls both temperature and humidity.

83. Time-temperature-humidity Controllers.—It is obvious that, when any but the self-contained humidity controllers are used, the temperature of the kiln must be regulated by means independent of the wet-bulb temperature control. It is possible to produce any desired fluctuations of temperature and humidity on a strictly time basis by a time-temperature-humidity controller with suitable cams, such as the one illustrated in Fig. 77.

84. Control of Humidity in Superheated-steam Kilns.—One special form of "humidity control" is found in superheated-

steam drying. As long as the temperature of the steam is kept above the boiling point, the steam is capable of drying substances in contact with it, and the difference between the steam temperature and the boiling point is a measure of the drying ability. Since the boiling point is fixed for any given barometric pressure (at normal pressure of 29.9 inches of mercury it is 212°F.) the kiln temperature for any given humidity is also fixed, and no other temperature will yield exactly that drying capacity.

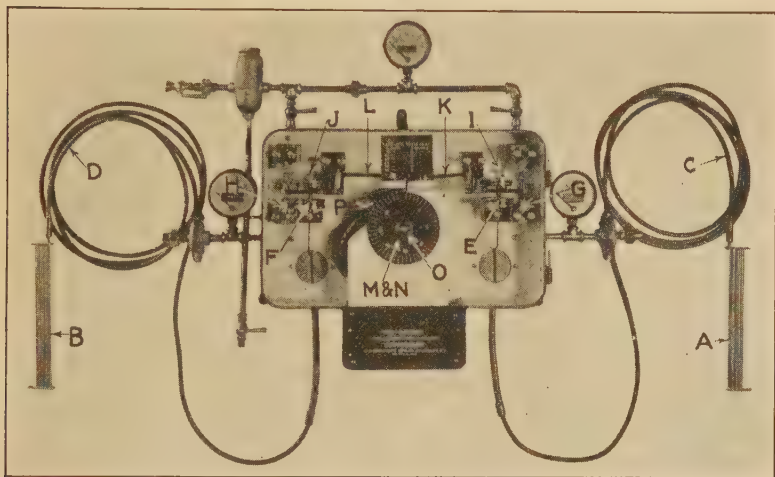


FIG. 77.—A time-temperature-humidity controller. (Courtesy, C. J. Tagliabue Mfg. Co.)

This instrument is intended to control the wet- and dry-bulb temperatures, and to change them, as the drying progresses, in accordance with any predetermined schedule. This result is secured by means of a pair of cams, driven by clockwork, which change the adjustment of the air valves controlling the flow of steam to the heating coils and the spray lines. The operation is as follows: Variations in pressure, resulting from changes in temperature of the bulbs *A* and *B*, are transmitted to the spring capsules *E* and *F* through the extension tubes *C* and *D*. *G* and *H* are the air valves, and *I* and *J* are the adjusting screws for making the initial temperature settings. Levers *K* and *L* are linked up with the adjusting screws so that movement of these levers up and down changes the temperature setting. The outer ends of the two levers rest upon the cams *M* and *N*, respectively. Only one cam shows in the illustration since the other one is directly back of it. These cams are mounted upon the post *O* which is rotated by a clockwork and train of gears. Various speeds of rotation can be secured by shifting the speed lever *P* along the sector. The profile, or face, of each cam is cut to give the desired variations in temperature as the cams are rotated, the levers *K* and *L* rising and falling in response to the changes in the cam profiles.

The thermostat on the heating coils, which now act as superheaters, is, therefore, set for the temperature corresponding to the desired drying capacity (amount of superheat or, loosely, "humidity"), and no further humidity control is needed. This makes the simplest possible arrangement, but the drying must be done at very high temperatures (225 to 240°F.). Further, unless care is used to provide ample steam through the jets, it is

impossible to expel all the air from the drying chamber and to keep fresh air from leaking in. The presence of air increases the drying capacity of the kiln atmosphere and provides faster drying than intended, with resulting trouble from drying defects. In one instance on record enough air was present in a commercial kiln to reduce the wet-bulb temperature to 180 instead of 212°F., where it should have been. Several similar instances, where an effort has been made to save steam, have been reported.

85. Humidities Recommended.—No definite rule can be laid down as to what humidities should be used. They depend upon the initial dryness of the lumber, the kind of wood, the temperatures used, and the purpose for which the lumber is being dried. The lower the humidity the more rapid the surface drying, and hence the transmission of moisture from the interior to the surface, provided the surface layers do not become so dry as to break up the flow of water to the surface. But with low humidities there is danger of injuring the lumber, and this must be guarded against.

In drying green or partly air-seasoned wood the humidity should be rather high (60 to 85 per cent) until the fiber-saturation point is passed, when it may be gradually lowered to from 40 to 20 per cent. In Chap. IX schedules will be given showing the proper humidities to use in the drying of various species of wood.

In drying air-dry lumber, a humidity of from 60 to 70 per cent should be used to begin with, and then it should be gradually lowered. Coniferous stock and some easily dried hardwoods used for rough work or where the presence of certain drying defects is not detrimental will endure lower humidities.

86. When and How Long to Steam Lumber in a Kiln.—It may be desirable or necessary for several reasons to raise the humidity in the kiln temporarily. This is usually done by admitting live or exhaust steam into the kiln chamber. For some purposes it is desirable to raise the humidity to 100 per cent; for other purposes, high humidities at less than saturation are preferable.

During all steaming periods the heat should be left on in the heating coils if the humidity can be raised to the desired amount. If this cannot be done, the amount of steam in the heating coils should be reduced. The steaming periods given below refer to the length of time during which the recommended humidities prevail and do not include the time required to raise the humid-

ity. The humidity and the temperature should be raised rapidly; hence, high-pressure steam is preferable for such treatments. After the lumber is steamed, the humidity must be lowered gradually.

It frequently happens that the steam (being lighter than air) accumulates at the top of the kiln, and it is difficult to reestablish proper drying conditions, particularly in a kiln with natural circulation. Vents in the ceiling are excellent for eliminating the moisture at the top of the kiln in such a case.

It is best not to steam bent stock at any time, or, if it is steamed, the operation must be carried on very carefully, as the stock will either straighten out, on account of swelling, or, if held securely, it will break if the steaming is carried on too long.

(a) *Steaming Green Lumber at the Beginning of the Run.*—The purpose of initial steaming is to heat the lumber through quickly so as to promote the rapid transfusion of moisture from the center outward at the very beginning. Without this initial steaming, the surface begins to dry as soon as the heat is turned on in the kiln, but the moisture from the interior comes out slowly; hence, checking and casehardening may occur.¹ Initial steaming does not, however, prevent checking or casehardening later during the run.

For steaming green lumber at the beginning of the run, 100 per cent humidity should be used for one hour for each inch of thickness. The temperature may safely be 25° higher than that at which drying is to begin, provided the stock is cooled to the operating temperature in saturated air.

(b) *Steaming Air-dry Lumber at the Beginning of the Run.*—The purpose of the initial steaming of air-dry lumber is to heat it through quickly and to make the wood plastic so as to relieve some of the stresses due to uneven drying. Steaming of air-dry lumber at a high humidity may set up strong internal stresses. These are due to expanding of the surface and may cause honeycombing. If the lumber is checked, the steaming should not be continued after the checks close up, or they may deepen on account of the tensile stresses set up in the interior.

If air-dry lumber contains less than 18 per cent moisture, it should not be steamed at 100 per cent humidity, but at 65 to 85 per cent for from 10 to 30 hours, the time depending upon the

¹ See again chap. III, p. 26, for the fallacy of theories on steaming lumber to remove the sap, starches, sugars, albuminous substances, etc.

moisture content and the thickness of the stock. The temperature during this steaming period should be between 160 and 180°F. For moisture contents much lower than 18 per cent the humidity should be between 60 and 70 per cent. If high humidities are used on dry stock, not only are temporary internal stresses set up but moisture is added which must later be evaporated.

Preliminary steaming is sometimes done in a separate cylinder or chamber. Care must be taken not to expose freshly steamed lumber suddenly for any length of time to lower temperatures (for reason, see footnote, page 156) or low humidities, for if this is done excessive surface drying and checking will result.

(c) *Steaming Lumber during Run to Hasten Drying.*—In drying certain kinds of lumber, especially thick stock of species difficult to dry, periodic steaming during the run for one-half to three hours may be beneficial. In such cases the humidity should be high enough to prevent surface drying (see curves in Fig. 11), but it is not necessary to add moisture to the surface layers unless they are much drier than the center of the stock. A temperature of 20 to 30° higher than the regular operating temperature at that stage of drying should be used. This treatment tends to spread the moisture from the center outward and to reestablish capillary flow in the surface layers, which hastens the drying.

(d) *Steaming to Kill Mold.*—This requires from one-half to two hours, at 100 per cent humidity and a temperature of about 165 or 170°F.

(e) *Steaming to Prevent Checking during the Run.*—If the lumber begins to check badly, it indicates that the surface is becoming too dry and that a higher humidity is needed. It is not necessary in such a case to steam the lumber for any length of time—just long enough to raise the humidity sufficiently to prevent further checking. The humidity should then be kept higher until danger of checking has passed.

(f) *Steaming to Relieve Casehardening.*—It may be desirable to relieve casehardening by steaming once or several times before the end of the run, especially thick stock and dense woods, since they have a tendency to caseharden severely. Usually it is not necessary until the surface checks begin to close up, or until a casehardening test shows that the prongs turn in *without* further drying. This indicates that the center is beginning to contract more than the surface layers. In this stage the wood should be subjected to a high temperature and to a humidity

high enough to prevent drying so as to relieve the stresses. At the end of the run it nearly always is advisable to relieve the stresses caused by uneven shrinkage.

Temperatures of from 165 to 185°F., irrespective of species or thickness, and humidities as follows should be used:

1. If center of stock contains over 17 per cent moisture, 100 per cent humidity for one-half to three hours should be used unless the stock is checked, in which case 85 to 95 per cent humidity should be used for ten to twenty hours.

2. If center of stock contains from 15 to 17 per cent moisture, 75 to 85 per cent humidity should be used.

3. If center of stock contains below 15 per cent moisture, 60 to 70 per cent humidity should be used.

In cases 2 and 3 the specified temperature and humidity should be maintained for from twenty to thirty hours, the time depending upon the thickness of the stock and the depth to which the outer set layer extends. The time limits refer to the time during which these temperatures and humidities are actually maintained and do not include the time required to reach those conditions. The length of time required in each case applies to stock 1 inch in thickness. Proportionately longer time is required for thicker stock. If 100 per cent humidity is used in these cases, the wood will absorb more moisture than necessary, especially at the very surface, which may even do damage by making the surface layers swell, and thus increase the internal stresses temporarily. What humidities to use so that the wood will not take on a great deal of moisture while it is being steamed can be determined from the moisture humidity curves in Fig. 11.

Care must be taken not to add too much moisture to the surface layers or the stresses may be reversed, as explained in Art. 34; or, if there are checks in the lumber, they will open up on further drying and will not close up later.

CHAPTER VIII

CIRCULATION AND PILING OF LUMBER IN A KILN

87. Why Circulation Is Necessary.—A moderate movement of the air in a kiln is absolutely necessary to obtain satisfactory drying results, for the following reasons:

1. To carry heat to the lumber in order to keep up its temperature so that the moisture will come out quickly and so that evaporation will continue. As previously explained, evaporation is always accompanied by the cooling of the air. Furthermore, certain parts of the kiln become cooler than other parts because of the loss of heat through the walls and ceiling; hence, a movement of air is necessary to keep up the temperature at these places. In winter, when frozen lumber is put in a kiln, a great deal of heat is required to heat the wood and the water in the wood. This heat must be supplied rapidly, or too much time will elapse before drying begins.

2. To carry away the excess moisture in the air. This is especially important at the beginning of the drying of green wood when large quantities of moisture are evaporated, or whenever it is necessary to maintain a high humidity for other reasons, as in drying common softwood lumber.

If the circulation is of sufficient velocity and uniformity to take care of these two requirements throughout the kiln, rapid and satisfactory drying can be secured. If the circulation is poor, some parts of the kiln will be much cooler than others. This is an undesirable condition, principally because the cooler parts will have a higher relative humidity. It is not uncommon to see damp places or "pockets" in a kiln charge where the lumber is not drying at all and where it may even be moldy. This condition denotes poor circulation. For example, if the temperature of the air as it enters the lumber pile is 130°F. and the humidity is 66 per cent, but at some point in the kiln the temperature is 115°F. (and this may easily happen), without gaining moisture through evaporation the air at that point will be saturated (in Fig. 66 follow the 30-grain curve from 130° and

66 per cent humidity up to where it strikes the 100 per cent humidity line). With additional moisture supplied by evaporation, the air would be saturated at an even higher temperature than 115°F., perhaps at 120°F.—a drop of only 10° below that of the entering air.

It is true that hot air and water vapor will diffuse without any perceptible circulation of the air, but this process is so slow that it cannot be relied upon for drying lumber.

It is only by thorough circulation that conditions can be kept fairly uniform in a kiln and all the lumber dried in approximately the same time. But even under the best conditions the lumber which first comes in contact with the heated air will dry slightly faster than that on the leaving-air side.

It is a common belief that circulation hastens the drying, but it does this only by supplying heat and carrying away moisture. Circulation in itself does not evaporate moisture. A breeze causes increased evaporation because it supplies heat and keeps down the humidity, especially *very close to the surface* of the object from which the moisture is evaporated. As stated in the previous chapter, when air is present, a layer of higher humidity hovers over wet surfaces and retards evaporation; a rapid movement of the air tears away some of this humidity and so *lowers the humidity* at the very surface of the lumber. This is illustrated diagrammatically in Fig. 67. Therefore, if a very rapid circulation is maintained in a kiln, a *higher humidity* is necessary than when the circulation is slow, in order to prevent checking and casehardening. In fact, a circulation more rapid than is necessary to carry away the evaporated moisture is not required in a kiln, for, while it might hasten surface evaporation, it would not hasten the transfusion of moisture to the surface, on which the speed of drying largely depends. There should, however, be a definite movement of air in the kiln.

The important thing to remember is: The drying should not be regulated by the circulation—that should always be active—but by the temperature and the humidity.

88. Methods of Producing Circulation.—Circulation of air in a kiln may be induced by gravity or by mechanical means.

(a) *By Gravity.*—Natural circulation brought about by the action of gravity is due to the rising of hot air (because it has expanded and has become lighter) whenever there is cooler air

to take its place. If no cooler air is present, the hot air does not rise, and circulation practically ceases.

It is believed by some that after the air has passed through the lumber it is heavier because of the moisture it has picked up and, therefore, seeks the lower levels. This is not the reason. It is heavier than when it entered the pile because it is cooler. Moist air is *lighter* than dry air of the same temperature because water vapor is lighter than air; and when water vapor is present in air it *replaces* the air, and the combination must be lighter.¹ The following figures show this:

One cubic meter of absolutely dry air (0 per cent humidity), at 140°F. and a barometric pressure of 760 millimeters, weighs 1,060.1 grams.

One cubic meter of air (including water vapor) at 100 per cent humidity, 140°F., and a barometric pressure of 760 millimeters, weighs 980.9 grams. Consequently, the moisture in the air counteracts, to a small degree, the downward tendency of the cooler air coming from the lumber.

The natural movement of air in a kiln by gravity has, in a way, certain advantages, since if there is any cool place in the kiln the air at this place has a tendency to fall, which means that warmer air will take its place. The principal objection to this method is that it often is too slow, especially if the lumber is not piled right or the kiln is not properly constructed.

(b) *By Mechanical Means.*—Forced circulation is often resorted to in order to increase the rate of air movement. It has the disadvantage that it seeks the lines of least resistance, irrespective of temperature and humidity, while the natural circulation is the greatest where differences in temperatures are the greatest. Mechanically induced air currents should, therefore, as far as possible, be made to travel in the same direction as that in which the air would go because of the influence of gravity alone. That is, the two should work together; otherwise they may oppose each other and stagnation result. If a blower is used in a lumber kiln, it is not safe to rely upon the momentum of the air to carry it uniformly to all parts, since the momentum is broken up as the air strikes the lumber. The air simply moves from points of high pressure to points of low pressure and,

¹ When the air is saturated, the water vapor in it weighs 0.623 times as much as the air it has displaced, irrespective of temperature. HAUSBRAND, E., "Drying by Means of Air and Steam," D. Van Nostrand Co., New York, 1901.

therefore, the lumber must be properly piled so that advantage may be taken of the circulation. Baffles may even be necessary to direct the flow of air current.

Two general methods are used for producing circulation "mechanically" in dry kilns: (1) jets or sprays of water or steam; and (2) power-driven fans and blowers.

Water sprays are used only in the water-spray kiln, of which they are the unique element. Steam sprays are used in practically every type of kiln. They serve to increase the humidity as well as the circulation, and are also used for preliminary steaming, intermittent steaming, and high-humidity treatments. They are very effective circulation producers when properly installed, but they are not nearly so efficient in this regard as power-driven fans or blowers. They are often used to stimulate circulation in kilns which are sluggish and which it is impossible or undesirable to remodel extensively.

Power-driven disc fans and centrifugal blowers are without question the most efficient producers of circulation at present available and are coming into increasing favor. Both types have long been used on various kinds of dryers, but the centrifugal blower has been the more popular for lumber-drying kilns. Very recently, however, a type of disc-fan kiln developed by the Forest Products Laboratory has proved a commercial success and has shown a remarkably high efficiency in moving air, or producing circulation.

89. Circulation in Progressive Kilns.—Just as all kilns can be divided into two broad classes, namely, progressive and compartment, so can the circulation be divided into "longitudinal" and "transverse." The former is usually associated with progressive kilns and the latter with compartment kilns, although progressive kilns can be operated with the main circulation crosswise (see Fig. 31). It should be pointed out, also, that the circulation is affected by many factors and does not always follow the direction shown by the arrows on drawings.

Figure 78 shows the important elements in a typical progressive kiln—the arrows are intended to indicate the general direction of the air circulation. Fresh air enters the kiln through the inlet duct at the dry end of the kiln, its humidity being increased by means of the steam jet, which also stimulates the air flow. The air rises through the heating coils and up into the lumber, and then travels in a longitudinal direction toward the green end,

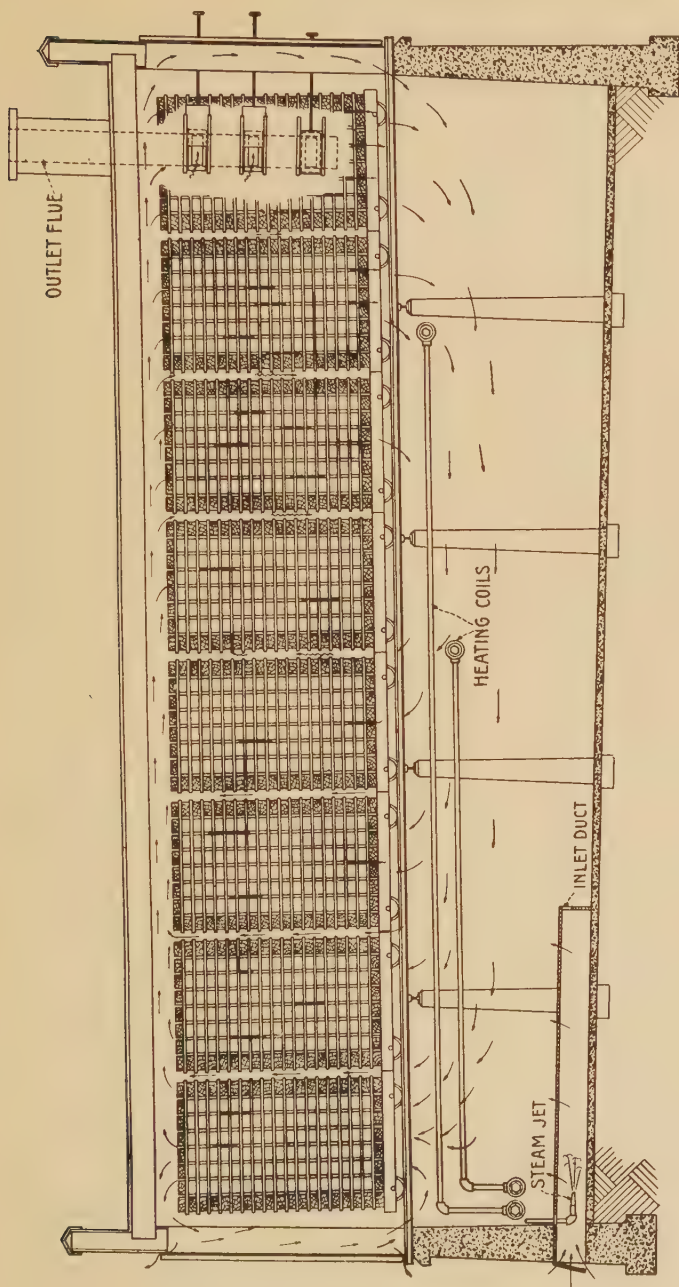


FIG. 78.—A typical ventilated progressive kiln.

This longitudinal sectional elevation shows the various elements of a kiln of this type. The lumber is cross piled, and the internal circulation is longitudinal. Fresh air enters at the dry end, and moisture-laden air escapes at the green end. A steam jet in the inlet duct may be used to stimulate the external circulation, but its effect will not be very important.

becoming cooler and more moist as it moves forward. Finally, upon reaching the green end, the air, now cold and nearly saturated, either passes up the outlet flue, through the dampered openings, or sinks down below the heating coils and makes its way back to the dry end, there to repeat the cycle. If this system could be followed with a reasonable degree of uniformity, and a circulation of the proper amount could be maintained, this type of kiln would be ideal for much of the simpler drying. The circulation is not very rapid, however, and it refuses to follow the arrows. The heating pipes at the green end offer resistance to the downward passage of the air, and eddy currents are set up throughout the length of the kiln, except possibly near the green end, by the hot air which rises from the heating coils. These eddies are aggravated by the tendency of the air in the piles, which is supposed to be traveling longitudinally, to fall down through the trucks and to interfere with the hot air coming up.

The circulation in this type of kiln is brought about mainly by gravity, or differences in the weight of the air. It is augmented, however, by the steam jet, which materially increases the flow of air through the inlet duct. The total effect of the jet is small, because the inlet duct has a small area compared with that of the entire kiln.

The inspiration of air through the inlet duct and its venting through the outlet flues (there is usually one on each side) are due to the fact that the air in the kiln is lighter (being warmer) than that outside and is, therefore, pushed upward through the outlet flues. The steam jet assists in the expiration. The "up and across, down and over" circulation from the dry end to the green end and back again is also caused by differences in the weight of the air. Here, however, the differences are between the air at one end and that at the other. The dry end of the kiln is kept hotter, by additional heating coils, and the air, therefore, rises at that end. At the green end the air is cooler, both because of fewer heating coils at that end and because of the evaporation of moisture accomplished by the air during its travel from the dry end. Consequently, the air descends at the green end, even if heating coils and other obstructions are present.

While the air is rising at the dry end and falling at the green end, it displaces some other air to make room for itself. The rising air pushes an equivalent amount of air along the kiln toward

the green end because there is no other way for it to go and because the falling air at the green end is making room for it. Similarly, the falling air displaces an equivalent quantity toward the dry end to fill the space made vacant by the hot air which has risen. The result is that a continuous circulation of air is set up—rising and falling at the dry and green ends respectively and moving longitudinally between them. Similar effects can be produced under a wide variety of conditions, the essentials being a source of heat and a cooling agent arranged in proper relation to each other in the same enclosure. This will be amplified in the discussion on compartment kilns.

As has already been mentioned, the principal circulation in a progressive kiln meets many little reverses and is in itself too sluggish to be of the greatest efficiency. Several schemes have been devised for increasing the circulation and for taking advantage of the natural forces which are ordinarily more or less in opposition to each other. One of these schemes is now being developed on a commercial scale by the Forest Products Laboratory. It consists essentially in producing a strong cross-circulation by means of steam sprays and baffles, just as is done in compartment kilns, and imposing this circulation upon the normal longitudinal circulation. Differences in temperature throughout the length of the kiln are produced by separate heating coils operated independently, and these temperature differences are so adjusted that the proper differences in humidity are also secured.

Recent experiments have shown that there is a very considerable cross circulation in certain types of ventilated double-track end-piled progressive kilns, and that it has an important effect in the drying.

Centrifugal blowers or large disc fans are sometimes used to produce the circulation in a progressive kiln. They are usually installed at the dry end of the kiln and equipped with external heating coils located in a large housing on the suction side of the fan. The air is blown directly into the kiln at the dry end and travels the full length of the kiln to the green end, where it is discharged into the atmosphere. Some kilns of this type have no doors at the green end; the air is allowed to blow out of the open end. No means are provided to secure recirculation of the air, and sometimes no provision is even made for humidity control. It is also very difficult to blow the air through the kiln at a high

velocity and have it go through the lumber pile because the easiest path is around the lumber, which is the way the air usually travel

90. Circulation in Compartment Kilns.—Compartment kilns are almost invariably designed for transverse circulation, but they do not always carry out the principle. Sometimes the main circulation persists in being longitudinal, possibly because of a heating system which does not heat uniformly, or because it is very sluggish for one reason or another not obvious to the designer.

In transverse circulation, by whatever means produced, the circulation takes place principally in a plane parallel to the ends of the kiln (that is, a cross-section), so that a particle of air, in moving across the kiln, will always remain the same distance from the end walls. For this type of circulation, end piling is better than cross-piling and should be used. When the lumber is edge stacked, the difference in drying efficiency between end piling and cross-piling is not so great as in flat stacking, but it is sufficient to justify the recommendation.

91. Circulation in a Natural-draught Compartment Kiln.—The general principles involved in transverse circulation can be understood by reference to Fig. 79, which is a diagrammatic sketch of a natural-draught compartment kiln, flat end piled. The inlet duct extends the full length of the kiln and is provided with a slotted top, so that the air may be uniformly distributed along its length. The steam jet may be used to assist the movement of the incoming air. The outlet flues are located at intervals along the sides of the kiln. The heating coils are grouped toward the center, and the lumber is piled with a central chimney. Canvas curtains may be provided to baffle the air, but they are not absolutely necessary. The side air passages are clear, except for the steam spray lines, and are extended below the heating coils by means of baffles.

The principal air circulation is upward through the heating coils, into the central chimney, laterally outward through the lumber (slightly downward also), and downward through the side air passages, then again up through the heating coils. A small amount of the circulation is, of course, inward through the inlet duct and outward through the outlet flues. The difference in weight between the hot air rising up in the center and the cool air falling through the side passages is sufficient to produce

a very appreciable circulation. This is increased very materially by the side steam sprays and also by the draft caused by the outlet flues.

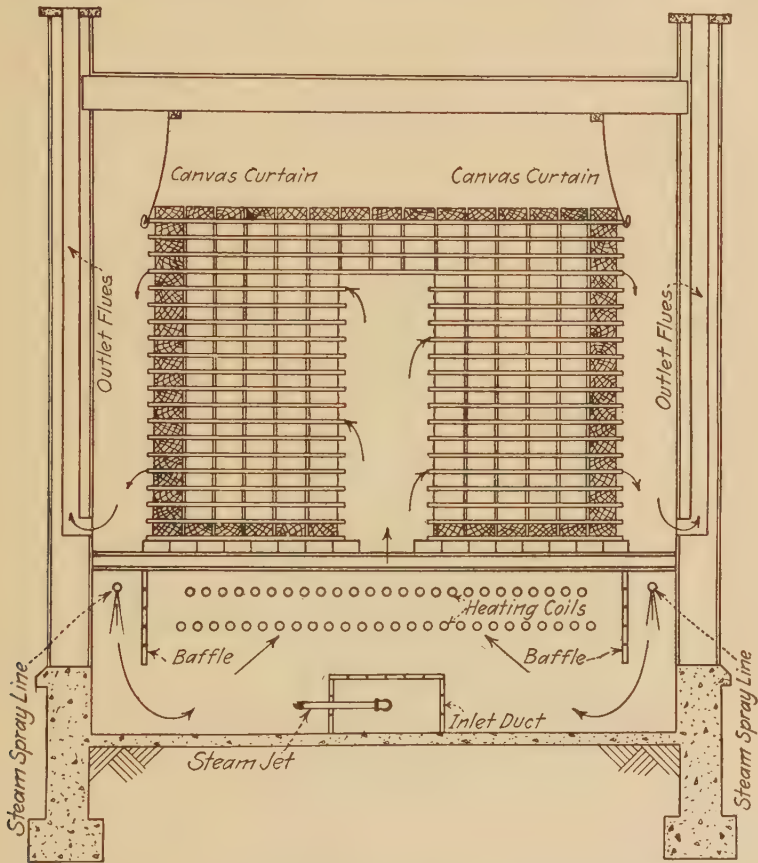


FIG. 79.—A typical ventilated compartment kiln. (From United States Department of Agriculture Bull. 1136, "Kiln Drying Handbook.")

This cross-section is not intended as a working drawing. It is intended merely to indicate how the various elements function. The stock is end piled, and the internal circulation is crosswise as shown by the arrows. Fresh air is continually entering through the inlet ducts and moisture-laden air is continually passing out through the outlet flues. This external circulation may be aided by the use of a steam jet in the inlet duct. Almost all of the air passing through the lumber drops down between the walls and baffles and returns again past the heating coils. This internal circulation is essential to the satisfactory operation of the kiln. It can be materially aided by the arrangement of baffles and steam spray lines as shown.

The general arrangement has been worked out very carefully so that the various forces available may be put to the best use. All of these forces assist the air in moving in the desired direction. They make its path as clear and short as possible. The

baffles prevent the hot air from rising up the sides and give the cool descending air a chance to fall unimpeded. Remarkably good results can be secured with a kiln constructed in this manner. The amount of steam used is comparatively large, when the

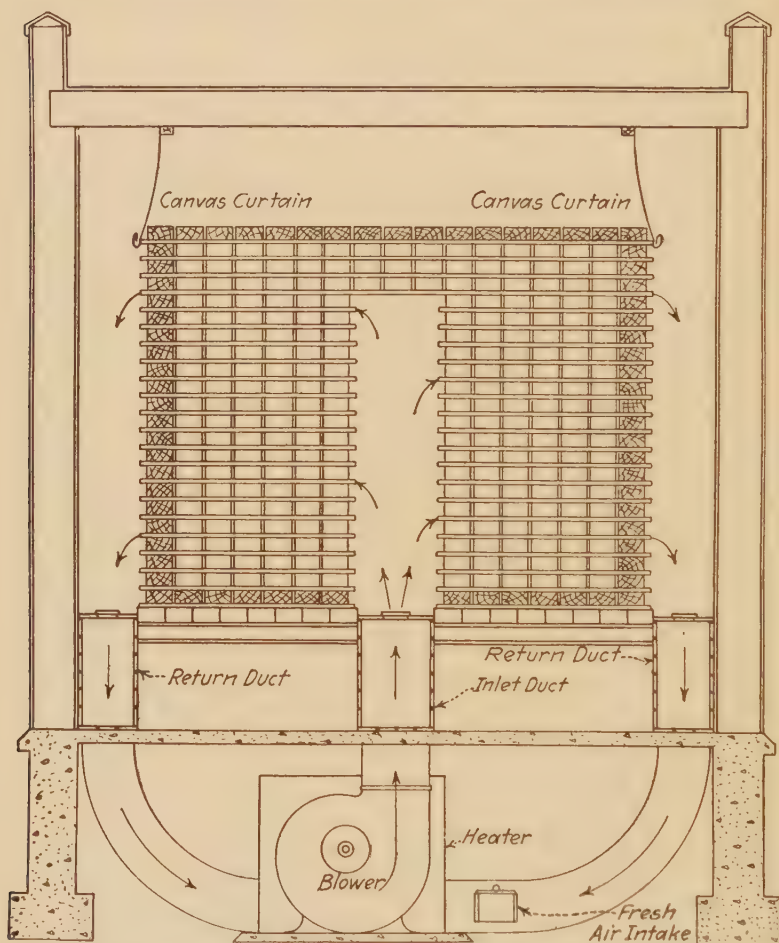


FIG. 80.—An external-blower compartment kiln. (From United States Department of Agriculture Bull. 1136, "Kiln Drying Handbook.")

The blower forces the air upward through the inlet duct, through the lumber as indicated by the arrows, downward into the return ducts, over the heating pipes in the heater, and back to the blower again. The fresh air intake is opened when it is desired to reduce the humidity in the kiln.

steam sprays are used to produce circulation, but this is offset to a large degree by the quicker drying resulting from the better circulation.

The circulation in almost all other types of compartment kilns is quite similar in direction to that in the natural-draught kiln just described, although the means for securing the circulation are different.

92. Circulation in a Blower Compartment Kiln.—An external-blower kiln is shown in diagrammatic cross-section in Fig. 80 and a typical centrifugal blower in Fig. 81. The internal circulation is just like that of the natural-draught kiln: upward

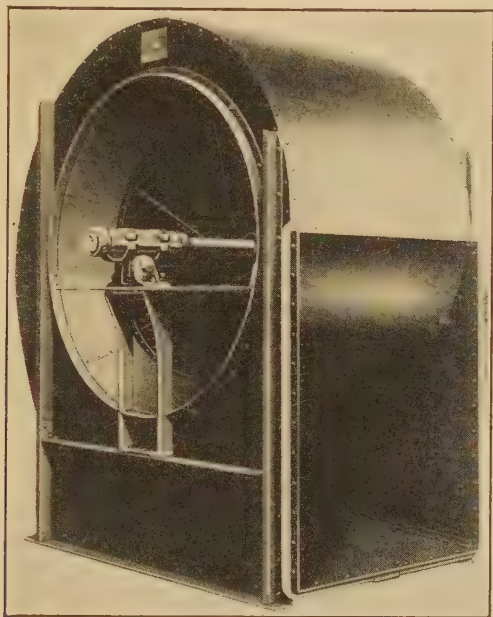


FIG. 81.—A centrifugal blower of the type commonly used in external-blower kilns. (*Courtesy, American Blower Co.*)

This type is usually referred to as "Multi-bladed." The particular blower illustrated carries the trade name "Sirocco."

through the central flue, laterally outward through the lumber, and downward along the side walls. Instead of returning underneath the lumber, however, the air is drawn through the return ducts to the blower, located outside of the kiln (usually at one end), passing first through the heating coils in the heater box. The blower then forces it through the inlet duct, from which it escapes into the central chimney again. Thus the cycle is repeated continuously. Steam jets are usually located in the heater, and sometimes steam-spray lines are mounted at the

sides of the kiln. Fresh air for reducing the humidity is taken in through an intake located on the suction side of the blower, the excess moist air passing out through leaks or through special outlet flues.

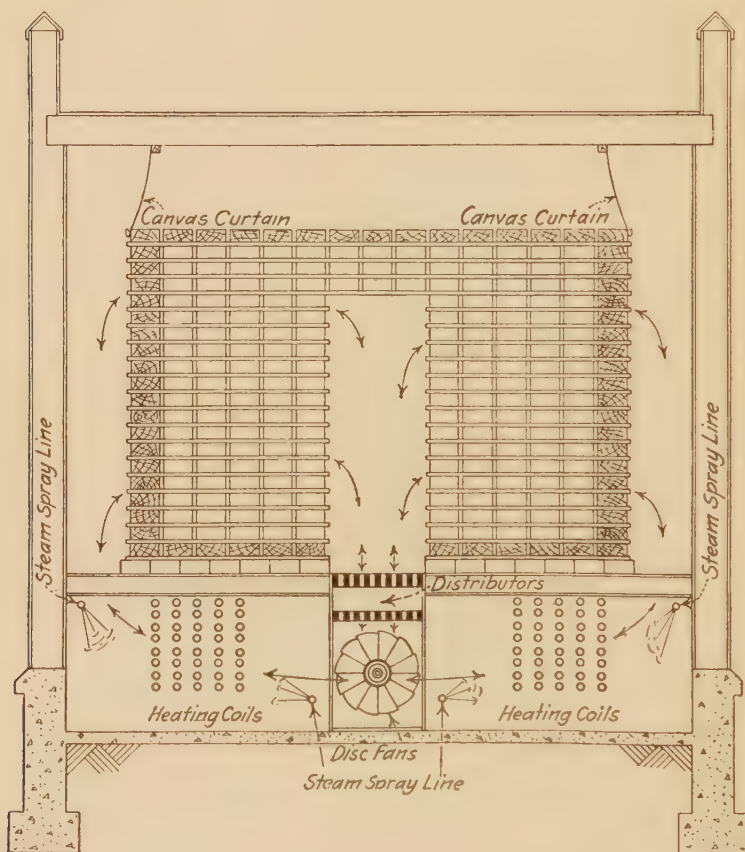


FIG. 82.—An internal-fan, forced-circulation, compartment kiln. (From United States Department of Agriculture Bull. 1136, "Kiln Drying Handbook.")

The general direction of the air circulation is crosswise, as indicated by the arrows. A shaft extends the entire length of the kiln and upon it are mounted a series of disc fans, spaced from 4 to 8 feet apart. These disc fans draw the air over the heating coils and force it upward through distributors extending the full length of the kiln. By reversing the direction of rotation of the fans, the direction of the air circulation may be reversed.

93. Circulation in an Internal-fan Kiln.—The circulation in the Forest Service internal-fan kiln, illustrated in Fig. 82, which is a cross-sectional sketch, is very similar to that of the natural-draught kiln, illustrated in Fig. 79, except for the fans and the reversing feature. The steam-spray lines are used only for

humidifying, but they are so located that they assist the circulation when they are in use. The disc fans are of the straight-blade type, as illustrated in Fig. 83, and are all mounted on a single shaft extending longitudinally from end to end of the kiln. They are usually spaced from 4 to 8 feet apart, and each one is surrounded by a box-like housing which serves to direct the flow of air. The shaft and fans are rotated at speeds ranging from 500 to 800 revolutions per minute by means of a motor located outside of the kiln. This motor is provided with a reversing switch so that the direction of rotation of the motor and shaft

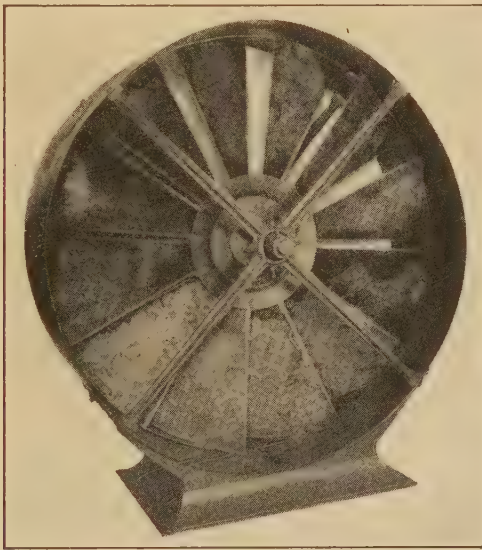


FIG. 83.—A straight-bladed disc fan and housing. (Courtesy, American Blower Co.)

This is the type of fan used in the internal-fan types of kiln. Usually, however, the housing is dispensed with, a row of fans being mounted direct upon a suitable line shaft.

may be reversed at will. When the fans are rotating in a clockwise direction, each fan draws air from the heating coils through the sides of the housing and delivers it, through the distributors, to the central chimney. The distributors serve to distribute the air flow uniformly throughout the length and width of this chimney. The upper pair of steam-spray lines is used when the circulation is in this direction. When the direction of rotation is reversed, the fans draw the air downward through the distributors and force it sideways on the heating coils, up

the side walls, inward through the lumber, and down the chimney to the distributors. The lower pair of steam-spray lines is then used. This reversing feature virtually eliminates the lag in drying rate between the entering-air edge and the leaving-air edge, producing more uniform and faster drying. The lag in the drying rate is caused by the fact that the air always cools and increases in humidity as it passes through the pile, losing some of its drying capacity and reducing the drying rate correspondingly. Thus, when the air is rising in the central chimney and passing laterally outward through the lumber, the inner edges of the pile will dry faster than the outer edges. A reversal of the circulation, however, balances this differential almost exactly, and makes the drying rate uniform throughout.

Disc fans are used primarily because reversal of the direction of rotation will reverse the air flow, which is not the case with centrifugal blowers. Further, installing them in the kiln and thus avoiding both long travel of the air through small ducts and the high resistance of the external heater units reduces the required pressure to a very low point and takes full advantage of the circulation produced by differences in the weight of the air. At this low pressure (probably about $\frac{1}{20}$ -inch water pressure) the disc fans are more efficient than the centrifugal fans. The net result is that a very fast, uniform circulation may be produced with a very small amount of power.

94. Circulation in a Water-spray Kiln.—The water-spray kiln, shown in cross-section in Fig. 34, and the pipe condenser kiln employ the same general type of circulation as the other compartment kilns already described. They take advantage of the natural circulation of the air, augmenting it, however, to a very great extent. Since the water-spray kiln is equipped with pipe condensers, for use near the end of the run when the circulation requirements are not so exacting, one description will suffice for both. The water sprays are located in spray chambers which run the full length of the kiln but open at the bottom as shown. The spray heads are spaced from 12 to 24 inches apart and point directly downward. They are sufficiently powerful to cool to the dew point all of the air passing them; the greater weight of this cooled air adds materially to the rate of circulation. In addition, the impact of the spray water upon the air exerts a strong pressure in the spray chamber. All of these forces acting together produce a very rapid circulation.

The pipe condensers, when used in place of the sprays, assist the circulation by cooling the air and thus increasing its weight. The action is not nearly so powerful, however, as that of the sprays because the air is not all cooled to its dew point, and the impact effect is lacking.

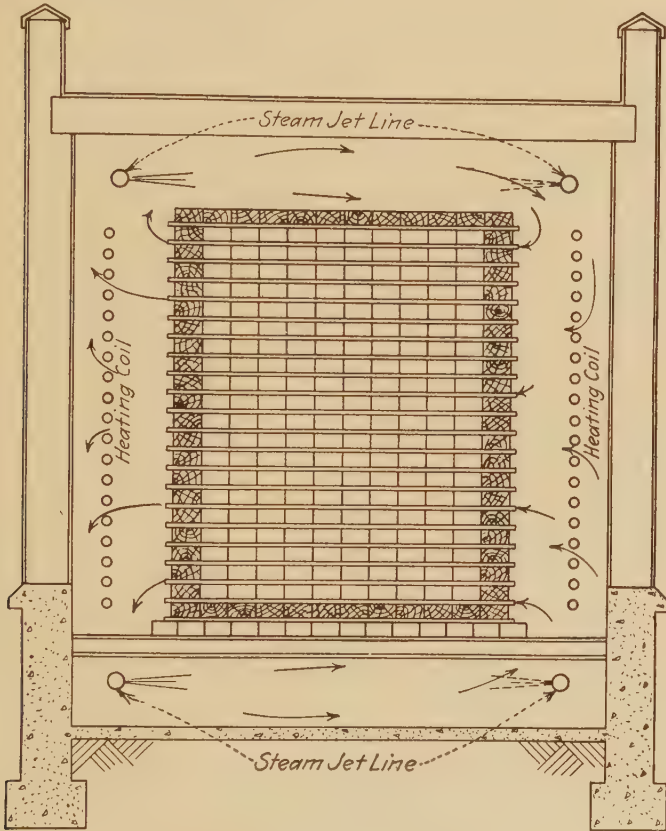


FIG. 84.—A superheated-steam kiln. (From United States Department of Agriculture Bull. 1136, "Kiln Drying Handbook.")

The two pairs of steam jet lines are used alternately, producing a reversible circulation. The arrows show the general direction of the flow of the steam when the two left-hand jet lines are on. Special controllers can be purchased which will open and close the respective jet lines at definite time intervals.

95. Circulation in a Superheated-steam Kiln.—The circulation in the superheated-steam kiln, illustrated in cross-section in Fig. 84, is novel in several ways: The atmosphere is steam, not air; the circulation is almost entirely produced by steam jets; the circulation is reversible, and passes entirely through the

single pile in a lateral direction. When the left pair of steam-jet lines is in action, the circulation takes the path illustrated. By shutting these lines off and turning on the right pair, the circulation is reversed. The circulation is extremely rapid and does not depend to any appreciable extent upon differences in the weight of the steam caused by changes in temperature.

96. Circulation in Connection with Various Methods of Stacking Lumber.—All of the illustrations and descriptions of compartment kilns discussed thus far have been of those types having a single row of flat-stacked, end-piled units. This type has been chosen chiefly because it is probably the most common one and because the principles of circulation can be well shown with it.

In double-track, end-piled, flat-stacked kilns two rows of piles or trucks are placed side by side. The circulation may be precisely the same as in the single-track kiln, the space between the trucks taking the place of the central chimney. Or it may be like that in the Sturtevant five-duct, double-track kiln, in which each truck has a central chimney. In this kiln an inlet duct is placed under each of the two rows of chimneys; an outlet one at each side wall; and a third one in the center between the two rows of trucks. The circulation in each pile is like that illustrated in the blower kiln (Fig. 80), and the effect is about the same as if two of these single-track kilns were placed side by side with no partition wall between, the two adjacent outlet ducts being combined. One blower serves the entire kiln. This design has the merit of great capacity in one unit, without sacrificing the advantage of the short air travel through the pile which is typical of single-track kilns with central chimneys in the piles.

Edge stacking is used to a great extent in the various softwood-producing regions. A typical truck of edge-stacked lumber is illustrated in Fig. 85. This happens to be a cross-piled truck; but if it were end piled, the only difference would be that the track would be at right angles to its present position. Edge stacking presents several unique circulation problems. In the first place, the air travel is long, about 7 or 8 feet, and the air must travel straight up and down. This seems simple enough at first thought since "hot air rises." Unfortunately, however, the hot air which starts rising through the pile of lumber becomes cooler and heavier as the moisture is evaporated from the lumber

and, consequently, its tendency to rise lessens rapidly. Further, it is usually much easier for the air to rise in the passages between the piles and the kiln walls than to force its way through the piles themselves. This is especially true of the usual form of kiln with a couple of layers of pipe clear across the kiln, and without special means for recirculation. Of course, if there are plenty of vents near the roof and enough inlet ducts below, the chimney

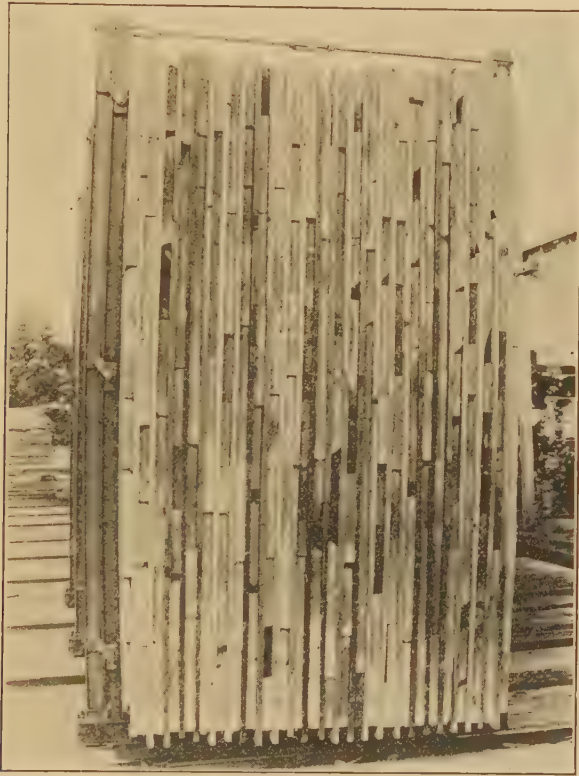


FIG. 85.—Vertically-piled lumber on a kiln-truck with shrinkage take-up devices.
(Courtesy, Forest Products Laboratory.)

effect of the hot kiln will produce a good external circulation, but this is not enough to produce good drying. The logical thing to do is to make the air *descend* through the piles and rise in the passages between them and the walls. This is the way it is generally done in external-blower kilns, but it would be somewhat difficult in natural-draught kilns because of the necessarily

awkward arrangement of the heating coils. No data are available to show the efficiency of a ventilated kiln so constructed.

97. How Circulation Is Determined.—The rate of circulation inside of the average kiln is so slow that almost all of the methods usually employed in the measurement of air velocities are not suitable. About the only method which proves satisfactory is to watch the drift of smoke in the kiln, and time its movement over a known distance by means of a stop watch. One of the special advantages of this method is that it shows clearly the *direction* of movement. It is, of course, necessary for the operator to be inside the kiln during the test.

Several different means are used for making the smoke. Tobacco smoke and the smoke from burning punk sticks or rope

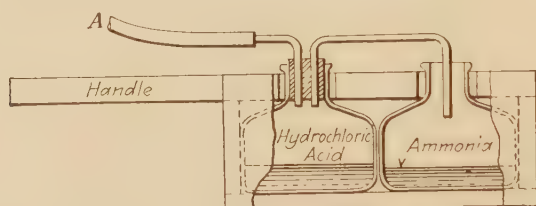


FIG. 86.—A smoke machine. (Courtesy, Forest Products Laboratory.)

An apparatus for producing chemical smoke. It consists of a small box and two bottles with a rubber stopper, two pieces of glass tubing, and a rubber tube *A* about two or three feet long. Blowing through the rubber tube with the mouth causes the fumes of the acid and the ammonia to mix and to form a dense white smoke, which issues from the mouth of the ammonia bottle. The drift of the smoke shows the amount and the direction of the air currents.

can be made to serve the purpose reasonably well. It is difficult, however, to get a sufficient volume of smoke; then, too, the fire risk is objectionable. There are cases, however, when one of these methods must be used, as, for instance, when it is necessary to determine the circulation at an inaccessible point. A few punk sticks or a small piece of rope can be tied to the end of a stick and held in many places which cannot otherwise be reached. In using smoke from any burning substance it must be remembered that it will tend to rise on account of its higher temperature and that the true circulation will not be indicated until the smoke has cooled to the temperature of the surrounding air.

A special form of smoke machine has been developed for dry-kiln work. This machine consists essentially of two small glass containers and several pieces of connecting tubing. One container is filled with hydrochloric acid and the other with ammonia (see Fig. 86). When air is blown into the mouthpiece,

the fumes from the two become mixed, producing a dense fog or smoke which will drift readily with the air current. To secure the proper results in smoke tests, the doors should all be closed and the kiln operated in the normal manner.

For higher velocities, such as those usually occurring in the flues of natural-draught kilns and in the interior of some types of forced circulation kilns, the Biram type of anemometer is suitable. This anemometer, illustrated in Fig. 87, is in essence a disc fan mounted on pivot bearings and provided with a revolu-

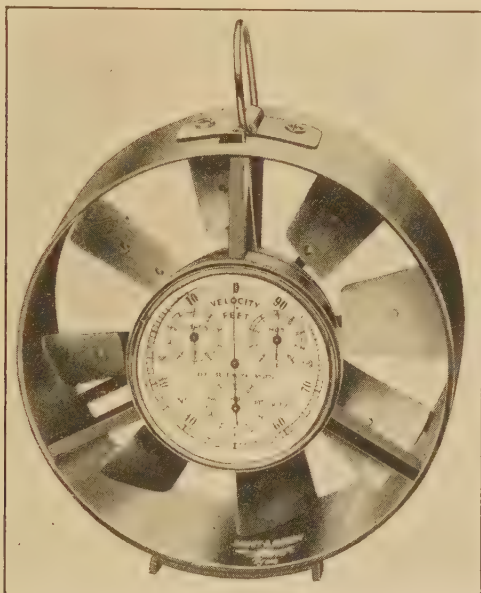


FIG. 87.—Biram type anemometer. (Courtesy, Taylor Instrument Co.)

This is the type of anemometer usually used to measure the air velocity in flues and ducts in dry kilns. It is very satisfactory for velocities of 200 feet per minute or more, but for low velocities some form of smoke machine should be used. The anemometer must be used with a watch, since it indicates total air movement only without reference to time.

tion counter. This counter is ordinarily in the form of a dial and pointer, one revolution of the pointer usually representing an air movement of 100 feet. It is necessary to use a watch with the anemometer, to determine the time corresponding to a certain air movement. It is customary to allow the anemometer to run a definite number of minutes, and then to divide the number of feet recorded by the number of minutes, the quotient being the velocity expressed in feet per minute. It must be remembered that the velocity in any duct varies through-

out the cross-section, it being the greatest at the center and the least along the sides, and that as a consequence a single reading will probably not represent a true average. For accurate results the cross-section of the duct should be divided off into squares about equal to the diameter of the anemometer and a



FIG. 88.—Testing the air circulation in a dry kiln. (*Courtesy, Forest Products Laboratory*).

In this kiln the air passes upward between the wall and the pile of lumber, and then horizontally through the lumber to the opposite wall. The illustration shows the smoke rising from the smoke machine and entering the pile of lumber.

reading taken on each square. This will seldom be necessary, however, in ordinary work. In using an anemometer in open places care must be exercised to set it with its axis parallel with the air movement. Otherwise it will register less than it should. The direction of the air movement may be determined by means of smoke.

Anemometers are imperfect in that the speed of the fan is not truly proportional to the air velocity over the entire range of usefulness of the instrument, making necessary a correction factor. This correction factor is determined by actual trial or calibration at the factory; a curve showing the amount of correction to be applied at different velocities should accompany the instrument.

Figure 88 illustrates the use of the smoke machine in determining the air flow in a narrow compartment kiln. The air rises from the heating coils at the right side of the kiln, passes horizontally through the pile, and down at the other side.

98. Desirability of Uniform Circulation.—Uniform circulation is essential to good drying. Everything possible, therefore, should be done to secure the utmost possible uniformity. At the first suggestion of trouble in drying, a study should be made of the circulation unless the remedy obviously lies elsewhere. Smoke tests should be made immediately, preferably with the smoke machine, throughout the kiln (this discussion applies to both progressive and compartment types, but is written with the latter particularly in mind) to determine the amount and direction of the circulation. The kiln should, of course, be closed and in normal operating condition. If the normal temperature and humidity are too great to permit the operator to work in the kiln, one or both may be lowered, care being taken to avoid a humidity low enough to injure the stock.

Smoke tests may be supplemented with hygrometer readings taken throughout the kiln if six or eight hygrometers are available. These should be distributed along the length of the kiln, half on the entering-air side and half on the leaving-air side, and read as nearly simultaneously as possible. If the dry-bulb readings on either side vary a great deal, but the dew points are about the same, the heating coils are probably defective. If the increase in humidity throughout the pile varies, the circulation is probably at fault. If the circulation is slow, the increase in humidity is apt to be large; but if it is practically stagnant, the humidity will usually be higher within than outside the pile. The smoke test will help to interpret the significance of the variations in the wet and dry-bulb readings. Longitudinal circulation in a compartment kiln usually indicates lack of uniformity in the heating, except in so far as it is caused by the location of inlet and vent openings. Eddies and similar dis-

turbances are usually caused by obstructions to the free flow of the air in the natural direction. (Lack of uniformity in the heating of kilns is discussed in Chap. VI.) Lack of uniformity in circulation may be caused by the temporary blocking of the air flow, by the design of the kiln, or by the methods of piling. The remedy in the first and third cases is obvious, but changing the kiln design to improve circulation requires careful study and some general knowledge of the principles involved. In compartment natural-draught kilns free-air passages, such as shown in Fig. 79, are the best possible assurance of freedom and uniformity of circulation. In blower kilns with external blowers, louvers or dampers are usually provided in the inlet or return ducts to permit the rate of air flow to be adjusted.

In the water-spray and pipe condenser kilns and in the superheated-steam kiln (which, of course, cannot be entered while in operation) uniformity of circulation is built into the design. In the internal-fan kiln the arrangement of the distributors and deflectors assures uniformity of circulation. Modification or adjustment of these can be made to meet unusual conditions.

Each individual circulation problem requires individual treatment and the exercise of good judgment. The most troublesome offenders are apt to be kilns with very sluggish circulation and those with excessive circulation. Stagnation and slow and unequal drying, often coupled with molding and staining, are apt to occur in kilns with low circulation. Extremely rapid circulation is difficult to control, largely on account of the jet action of the rapidly moving air, which precludes the uniform distribution of the air through the pile. Very large ducts are essential if large quantities of air are to be handled by forced draft.

99. Rate of Circulation Desirable.—The rate of circulation is expressed in two ways: (1) by the rate of air movement through the lumber, in feet per minute; and (2) by the number of changes of air in the kiln per hour or per minute. The former is the more logical method, but the latter is still much used. By the latter method the rate is usually calculated on the basis of the volume of the empty kiln above the rails. It is usually used with natural-draught and external-blower kilns. In connection with the latter it has some significance, since it is a direct measure of the volume of air handled by the blower. With natural-draught kilns, however, it is usually based on the external circulation only (that entering the kiln through the inlet duct and

leaving through the vents) and neglects entirely the recirculation which should be much greater than the external circulation. The calculation is made as follows: Calculate the volume of air entering the kiln per minute by multiplying the area of the ducts by the average velocity of the air passing through them, in feet per minute. Divide this by the volume, empty, of the kiln above the rails; the quotient will be the number of air changes per minute. Multiplying by 60 converts it to air changes per hour. For example, a kiln 40 feet long, 15 feet wide, and 10 feet high above the rails (volume 6,000 cubic feet) has an inlet duct 2 feet wide and 2 feet deep (area 4 square feet) through which the air moves at an average velocity of 600 feet per minute. The volume of air aspirated per minute is 4×600 , or 2,400 cubic feet. The number of air changes per minute is then $\frac{2,400}{6,000} = 0.4$, or 24 changes per hour.

The rate of air movement through the pile can be determined by timing the travel of smoke with a stop watch or by calculating the rate of movement through a duct of known area. For instance, suppose that, in the kiln shown in Fig. 79, the width of the passage between the lumber and the side wall is 1 foot and that an anemometer reading shows an average velocity of 50 feet per minute. The volume of air flowing down this passage per foot of kiln length will be $1 \times 50 = 50$ cubic feet per minute. There are twenty courses of 1-inch stickers, making a total area, per foot of kiln length, of $20 \times \frac{1}{12} = 1\frac{2}{3}$ square feet, through which the air must flow to reach the passage between the wall and the pile. The velocity of flow will then average $\frac{50}{1\frac{2}{3}} = 30$ feet per minute through the pile.

The proper rate of circulation for any given type of kiln or any class of drying is difficult to determine in actual figures. Natural-draught kilns, operating on air-dry stock, are producing reasonably satisfactory results with velocities as low as 5 feet per minute or less within the piles. However, uniformity of drying cannot be expected at this low rate—the entering-air side of the pile will be dry long before the leaving-air side.

In kiln drying green and other refractory woods, the air should travel at a rate per foot of 5 to 10 times the total number of feet it travels through the pile. The higher rate is very desirable while the stock is yet green and high humidities

must be maintained; the lower rate may be used after the stock has dried down below the fiber-saturation point. About the same rates of circulation are being used with success in the fast drying of upper grades of softwoods.

In the drying of the common grades of Douglas fir and southern pine, very high velocities are necessary because of the high humidities which must be maintained to keep the knots from falling out; the very rapid drying rate obtained, which causes a large temperature drop and humidity rise in the air on its passage through the pile; and the need for great uniformity in drying brought about by the fact that the drying is stopped at about 15 per cent, and no opportunity is presented for any equalization of moisture.

The circulation should be reversible and should average about 75 feet per minute for flat-piled stock with a short air travel of about 3 feet. For edge-stacked stock the velocity should be greater because of the longer air travel (7 to 8 feet). It should probably be at least 100 feet per minute.

100. Piling Lumber in a Kiln.—In piling lumber in a kiln two things should be kept in mind: (1) to arrange the pieces so as to facilitate the circulation as much as possible; and (2) to get as much lumber into the kiln as is consistent with its proper operation. The first of these is the more important.

The manner in which the lumber is piled in a kiln influences the circulation and rate of drying just as much as the construction of the kiln.

There are three general ways of piling lumber:

(a) *Flat*.—This is the most common method and also the simplest. The lumber is piled on trucks which are run into the kiln, or on horses, or on the operating floor. The piles may be built up with the ends of the lumber showing at the doors. This method is called "end piling," as distinguished from "cross-piling," in which the lumber is placed crosswise in the kiln. Kiln manufacturers usually furnish equipment for either method of piling, the choice being optional with the purchaser, although only one method is the correct one for a particular type of kiln.

In progressive kilns with longitudinal circulation the lumber is usually cross-piled so that the air can pass through the lumber piles parallel to the stickers (see Figs. 30 and 89). In end piling in these kilns the stickers obstruct the horizontal movement of the air from the dry to the green end. It should be pointed out,

however, that important cross-circulation occurs in addition to the longitudinal circulation. In progressive kilns with transverse circulation, the lumber should be end piled as in Fig. 31.

End piling is often used in progressive kilns simply because it takes up less room. A truck of 12-foot material can be butted up against a truck of 16-foot material without loss of space, while in cross-piling, if the width of the kiln is satisfactory for 16-foot material, shorter stock will not fill all the space. However, a kiln is not a place for storing lumber but an apparatus for seasoning it properly.

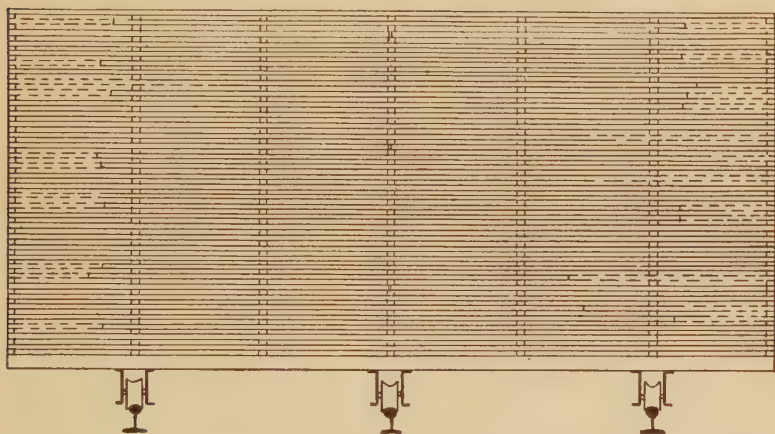


FIG. 89.—Proper method of cross-piling lumber of varying lengths on car.

Some operators prefer end piling if the kilns have more than one track because they can put the material which dries more quickly on one track, and that which dries more slowly on another track. Then they can run the easily dried lumber through more rapidly. This means, however, that the conditions in the kiln must not be maintained so that the drying is as rapid as permissible for the stock which is easily dried, or the more slowly drying stock will be subjected to too severe conditions.

In compartment kilns with air vents or condensers at the sides, the lumber should be end piled with the stickers placed crosswise in the kiln. This arrangement permits a horizontal movement of the air from the interior toward the side walls, and gives the cooler air which would not naturally rise to the top a chance to get out of the pile, preventing stagnation within the pile (see Figs. 33, 34, 35, 79, and 90).

The relation of the method of piling to the rate and uniformity of drying was forcibly brought out in a series of tests at the Forest Products Laboratory. In a kiln having transverse circulation, lumber was piled both endwise and crosswise. A curtain was dropped from the ceiling between the two piles in such a way that each pile dried according to the same temperature and humidity. Temperature and humidity readings were taken daily, at differ-

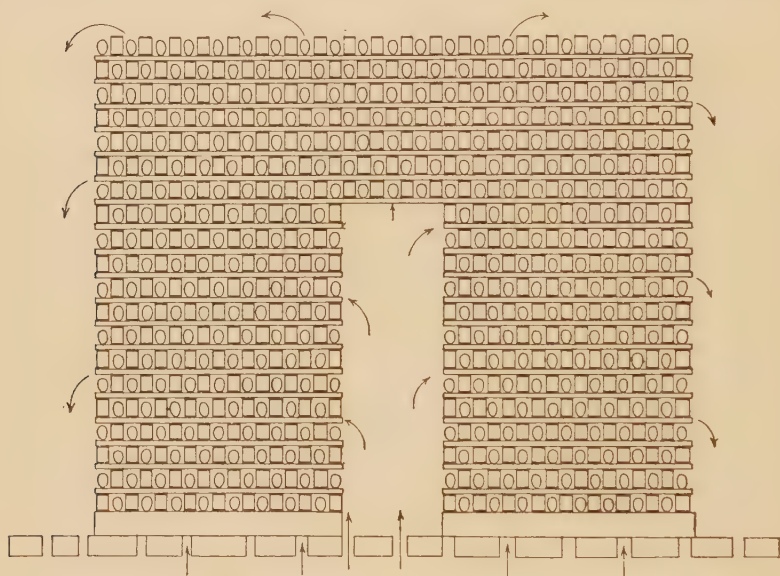


FIG. 90.—Ends of large wagon spokes piled on floor of kiln with vertical-lateral circulation. "Chimney" in center of pile.

ent parts of each pile. On the eighth day, for example, the readings were as follows:

CROSS-PILED LUMBER		END-PILED LUMBER	
Center of the pile.....	110°F.	Center of the pile.....	142°F.
Underneath.....	168°F.	Underneath.....	152°F.
Above.....	146°F.	Above.....	146°F.

The difference in temperature between the center and the bottom of the first pile (cross-piled) was 58°, while in the second pile (end-piled) the difference was only 10°.

Naturally, such differences in temperature at various parts of the piles had a decided effect on the rate and uniformity of drying. The end-piled stock dried in ten days from a moisture

content of 30 per cent to a maximum moisture content of 6 per cent. The stock piled crosswise dried in thirteen days from 30 per cent down to 12 per cent.

The lesson is obvious. Lumber should be piled to suit the circulation in the kiln.

Flat-piled lumber should be stacked carefully with sufficient spaces between the edges of the boards and between successive layers. With the air entering the lumber piles from underneath, the spaces between the edges of the boards should be from one-quarter to one-third of the width of the boards. In piling strips, several may be placed close together and a relatively wide space left between the groups of strips in the same tiers. If the air enters more or less from the sides and goes horizontally through the piles, less space is necessary between the edges of the boards than if the circulation is more nearly vertical.

The stickers, or crossers, should be arranged in vertical rows over rigid and properly aligned bearings. A row of stickers should be placed flush with the ends of the boards, so as to leave no free unsupported ends (see Fig. 89). The spacing between the stickers should not exceed 4 feet for heavy material and 1-inch softwoods and 3 feet for 1-inch hardwoods. Thinner material or lumber that warps easily should have stickers every 2 feet. It should be remembered that it is the weight of the lumber itself distributed over the stickers which keeps it straight, since lumber has a natural tendency to curve and twist as it dries.

The stickers should be dressed to a uniform thickness of $\frac{7}{8}$ or 1 inch. They should be from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches wide. Wide boards or laths should never be used for crossers in a kiln.

If the lumber which is being put into a kiln is of different lengths, it is best to build up the pile with square ends, as in Fig. 89. This avoids large open spaces in the kiln along which the air can short-circuit, especially in progressive kilns with longitudinal circulation. The next best thing to do is to sort out the lumber, piling the various lengths on separate trucks. It is poor practice to pile long lumber on shorter material, leaving overhanging ends.

If the piles of lumber in a compartment or progressive kiln are very wide, it usually is advisable to leave a "chimney" in the middle extending two-thirds of the distance toward the top of the piles (Fig. 91) or to leave comparatively wide spaces between the boards. The chimney permits the rapid ascent of

air to the upper half of the pile where the air spreads out and more uniform drying is attained.

If the lumber is of a high grade, and the heating coils are underneath the lumber, the first course should be of poorer material than the other courses so as to protect the good lumber against direct radiation.

In some cases it is necessary to weight down the top of the pile to keep the upper courses straight.

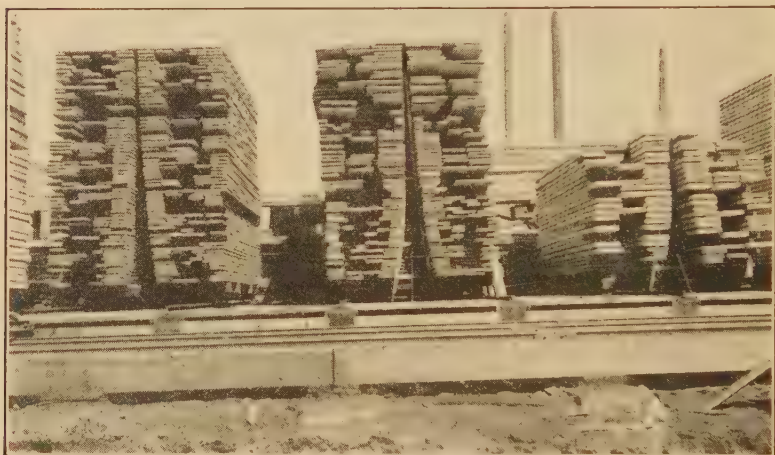


FIG. 91.—Lumber piled on kiln trucks with "chimney," in center of piles.
(Courtesy, Forest Products Laboratory.)

(b) *Vertical*.—In drying yellow pine of the South and Douglas fir and other conifers on the Pacific Coast vertical piling is often used. Several systems are used for stacking lumber vertically. The most common are those in which the lumber slides on an inclined apron which raises each layer vertically when filled up; those in which the whole pile of lumber is piled on an inclined frame which is tilted vertically when the pile is completed; and those in which the lumber slides along vertical guides in place in the pile. Figure 92 shows one kind of vertical stacker in operation. Of course, the lumber must be held in position firmly. Shrinkage is taken care of either by the tilting of the piles sideways and thus tightening the pile, or by shrinkage-take-up devices. Figure 85 illustrates a kiln truck which automatically adjusts for shrinkage. The weight of its pile rests on a beam which is connected with the lower end of the outer vertical stand-

ards on the left side. These exert a pressure to the right on the standards next to them.

With the stickers and boards vertical, the moving air strikes both faces of the lumber equally. Furthermore, no space is necessary between the edges of the lumber, and so the capacity is increased. The chief advantage of this method of piling is that no spacing is necessary between edges, and the piling can be done mechanically at a comparatively low cost. The disadvantages are that there usually are only two or three stickers per kiln truck length and none at the very ends of the boards; hence, the lumber tends to warp, and it is difficult to take down a pile unless a mechanical unstacker is used.

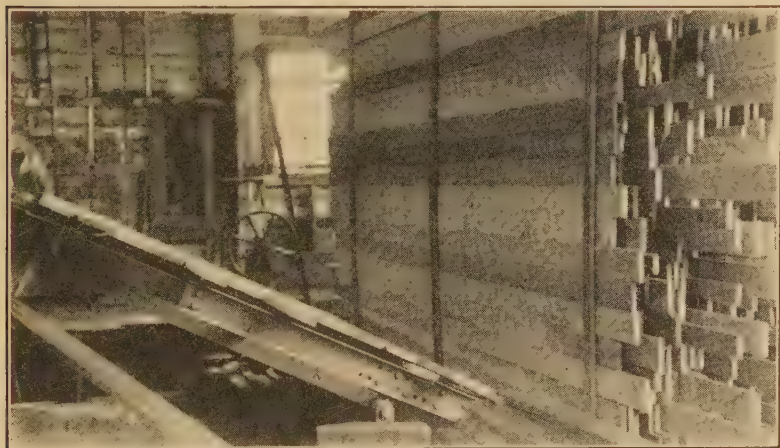


FIG. 92.—Vertical lumber stacker.

(c) *Inclined*.—A method of piling, as illustrated in Fig. 34, has been developed at the Forest Products Laboratory. The air rises in a central flue but is prevented from going out at the top by curtains. It, therefore, enters the lumber piles and moves outward and *downward*, which is the most logical course for the gradually cooling air. No space is necessary between the edges of the boards. This method is especially adaptable to green lumber. On account of the newness of this method and the difficulty experienced in piling the lumber at an incline, it is not yet used on a large scale.

A unique way of combining inclined piling with reversible circulation is used by a firm drying redwood on the Pacific Coast.

At the green end of the kiln the heating coils are at the sides of the kiln, the hot air rising between kiln trucks and the walls as shown in Fig. 93A and passing downward through the lumber toward the center. Toward the dry end, where there is less cooling, because of evaporation, the heating coils are at the center, and the air goes upward through the lumber toward the walls where it goes downward to be recirculated, as shown in Fig. 93B. In this kiln the circulation reverses itself automatically.

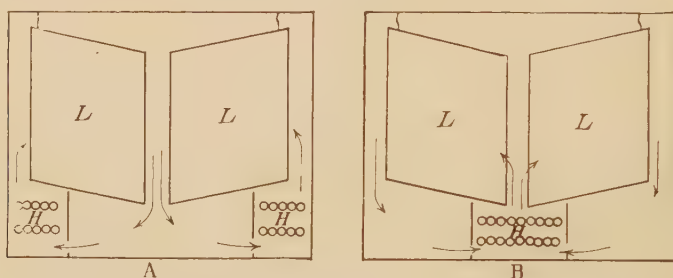


Fig. 93.—Diagrammatic section of progressive kiln in which piling and location of heating coils conform to natural tendency for circulation.

A, near green end; B, near dry end of kiln; L, lumber piled on incline; H, heating coils.

101. Piling Miscellaneous Shapes in a Kiln.—Under this heading come articles like veneer, plywood, spokes, rims, dimension stock, gun stocks, shoe lasts, staves, heading, shingles, and lath.

In drying veneers and plywood panels it is more important than with most other material to arrange the stock so that the stickers are parallel with the direction of the circulation as far as possible. The stickers usually used are less than $\frac{7}{8}$ inch thick, but it is not wise to have them as thin as $\frac{1}{2}$ inch, since veneer often curls up a little at the edges, shutting out the circulation to a greater or less extent. Because of the large surfaces exposed, a good circulation of air is of vital importance in kiln drying such material.

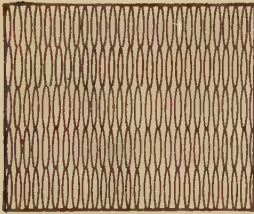
It is preferable to pile turned spokes with the heads and shanks alternating, the horizontal spacing being from $\frac{1}{4}$ to $\frac{1}{2}$ inch at the ends (see Fig. 90). Because the shank is narrower than the head, $\frac{3}{4}$ -inch stickers are sufficiently thick.

Bent rims take up a great deal of room, since usually nothing can be put inside of them. The rims are usually piled flat with two stickers parallel to the tie strips between courses.

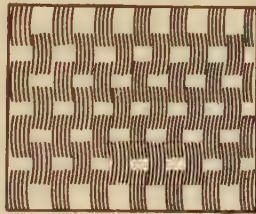
Small dimension stock and gun stocks should be fitted together in layers so as to occupy a minimum of space and yet allow from $\frac{1}{2}$ to 1 inch between pieces. Since such small stock twists and bends more easily in drying than larger material, a sufficient number of stickers must be used. The crisscross method of piling without stickers is not recommended because of the uneven



FIG. 94. —Staves stacked vertically on kiln trucks. (*California Barrel Co., Arcata, Calif.*)



A



B

FIG. 95.—Top view of two methods of stacking staves on kiln trucks.

thickness of such stock and the large amount of surface covered up where pieces cross. If this method is used, more space must be allowed between pieces than when stickers are used. Dimension stock may also be dried in bundles with thin stickers between the layers in the bundles, provided the circulation in the kiln is good.

Turned shoe-last blocks are difficult to pile on account of their curved and irregular shape. By the use of appropriate stickers and by alternating the ends of the lasts, a fairly high pile can be built up, however.

Short staves, as for tubs and pails, are often piled in special racks made for the purpose by manufacturers of dry-kiln accessories. Barrel staves often are set vertically in cages, as in Fig. 94. The best arrangement in such cases is to alternate the curvature, as in Fig. 95A, which shows a top view, although for speed in handling they are sometimes grouped and then staggered across the truck, as in Fig. 95B.

Shingles and lath are dried in packages. The kiln drying of shingles presents perplexing problems, since the packages are bound tight, and the moisture comes out very slowly unless very high temperatures are used. This makes the wood brittle and also causes collapse, or "crimps," especially in shingles from the wet butt logs of western red cedar.

In piling material of any shape it should be constantly kept in mind that sufficient space should be left for circulation in the right direction.

Occasionally, hub blocks, last blocks, insulator pins, short spokes, and other short pieces are dumped on the kiln floor or in cribs which are run into the kiln. Obviously, the circulation is poor through such a pile, and the time required for drying is longer than when the material is properly piled.

CHAPTER IX

KILN SELECTION, LAYOUT, AND CONSTRUCTION

102. Selection of Type of Kilns. (a) *General Considerations Governing Selection of Kilns.*—To give the best service, each battery of kilns must be designed to meet the specific requirements of the plant which it is to serve. Intelligent consideration must be given to surrounding conditions and each one properly weighed in making a final decision as to the type, location, number, layout, and construction of the kilns. The most important factors in determining the type of kiln to use are the amount and the kind of lumber to be dried and its condition when it is put into the kiln.

(b) *Progressive versus Compartment Kilns.*—Progressive kilns are limited in their application to comparatively simple drying. They are used in the drying, green from the saw, of easily dried softwoods and of air-seasoned hardwoods. They are, in general, adapted to conditions where large amounts of the same kind and thickness of wood to be dried become available continuously. To procure the necessary gradients of temperature, humidity, and moisture content, progressive kilns are usually quite long—100 feet or more. Cross-piling is the more common practice in progressive kilns. However, especially in the southern-pine region, many progressive kilns are arranged for end piling. When proper provision for cross-circulation through the piles is made, end piling will give satisfactory results. Practically all progressive kilns are of the ventilated type and are extremely easy to operate. The accuracy of control is, however, correspondingly small. The amount of track required for a battery of progressive kilns is comparatively small, since only one or two truck loads of lumber are put in, or taken out, at one time.

Compartment kilns are of many types and are adapted to a wide range of drying conditions. The accuracy of control is much greater than that in progressive kilns, and a correspondingly greater amount of time and attention is required for their operation. The accuracy of control and the skill required to

secure the best results vary considerably with the individual types. In general, the kilns which are capable of the most accurate control require, likewise, the most skilled operation to get the best results. Compartment kilns may be of almost any reasonable length desired, since the length does not have any very important relation to the securing of the desired conditions in the kiln. It is, however, difficult to maintain these conditions with great accuracy throughout the length of a very long kiln. Compartment kilns are usually between 40 and 100 feet long. Where a large variety of drying requirements must be met, it is usual to have a battery of a comparatively large number of small kilns. Where the variety is less, a smaller number of larger ones may be used. The design of a compartment kiln is much more flexible than that of a progressive kiln. Compartment kilns usually employ cross-circulation. End piling is considered best for this type of circulation, although many compartment kilns with cross-piling are in successful operation. The track-age required for compartment kilns is usually much greater than that required for progressive kilns of the same size.

The present tendency is distinctly toward compartment kilns and away from progressive kilns, even for those classes of drying for which progressive kilns are specially adapted.

(c) *Forced-circulation versus Natural-draft Kilns.*—Forced-circulation kilns are preferable to natural-draft kilns for the drying of green wood of species which are difficult to dry, such as most of the hardwoods used in furniture, and for other exacting work, such as seasoning common grades of Douglas fir and southern pine, green from the saw. They may also be used for the seasoning of easily dried woods. The blower and internal-fan kilns have the widest application of all the various kiln types, in that they can be adapted to more kinds of drying than the other types.

The water-spray kiln, invented by H. D. Tiemann and developed at the Forest Products Laboratory, is a forced-circulation kiln which can be easily controlled. It finds its greatest sphere of usefulness in the drying of thick, green hardwoods, such as oak and other woods which are difficult to season. For this work the accuracy of control outweighs the higher first cost and operating costs.

(d) *Superheated-steam Kilns.*—For some softwood drying, notably the drying of clear grades of Douglas fir, the superheated-

steam kiln has met with favor from a number of sawmill operators. The high temperatures used (usually above 225°F.), coupled with an extremely rapid circulation, produce a very fast drying rate. To maintain these conditions requires a large amount of steam. Their use no doubt increases the rate of depreciation of the kiln buildings and equipment.

(e) *Miscellaneous Factors Governing Selection of the Kilns.*—The purpose for which the dried stock is to be used must be given consideration in the selection of the type of kiln. Where the strength of the wood is of the utmost importance, such, for instance, as in aircraft and in some classes of sporting goods, special low-temperature schedules must be used, and the regulation must be accurate. Forced-circulation kilns are recommended for this work. For fine furniture, pianos, and similar high-grade uses, the stock must be dried unusually carefully and kilns better than the average used.

An adequate supply of steam and, in the water-spray kiln, of water, are important. These factors should be investigated thoroughly before the plans are carried beyond the preliminary stage.

For high-temperature drying, it is essential that high-pressure steam be available. For low-temperature drying, exhaust steam or low-pressure live steam may be used. The dividing line is not sharp. It is determined to some extent by the cost of live steam, the pressure of the exhaust steam and the quantity available, and the cost of the added amount of radiation required when low-pressure steam is used. Speaking broadly, high-pressure steam (over 10 pounds per square inch gage) should be used for all temperatures over 150°F.

The permanence of the operation will usually be one of the determining factors in the selection of the material from which the kilns are to be built. The present practice is to use permanent forms of construction wherever the life of the plant is over ten years. However, this is influenced largely by the individual ideas of the builders and owners, and no hard-and-fast rule will apply. The first cost of the kiln also has an important bearing upon the selection of the materials of construction. As the operative efficiency of kilns, when properly constructed of the various materials in common use, is almost identical, it does not have a great deal of weight in the selection of the material.

103. Location of Kilns.—The site of the kilns is too frequently determined by conditions beyond control, such as limited space available. When there is any choice, however, mature consideration should be given to the selection of the site, so that the greatest possible efficiency may be secured.

The nature of the ground and its contour determine in large measure the cost of excavation and foundations. A reasonably flat, well-drained area, with sufficiently firm soil to make the use of wide footings or even piling foundations unnecessary, is the most desirable. The matter of drainage is of especial importance where unusual depth below the rails is required, particularly with the water-spray kiln, because of the water wells and the need for overflows and drains from them.

The elevation of the site should be such that the tracks match up with the yard and factory trackage or tram systems with the minimum expense for excavation, platforms, trestles, and similar construction. The kilns should be made to fit into the yard and factory system so that the amount of handling and moving of the stock to and through them will be as little as possible. The kilns will thus be situated normally between the yard or sidings and the factory or dry storage, and the general principle followed that the stock shall always move in the same general direction as nearly as is possible. In large sawmill installations, where there are automatic stackers and unstackers, the kilns and these stackers and unstackers are usually grouped close together, the individual layout depending upon the general plant design.

The kilns should be located as near to the power plant as is compatible with the surrounding conditions so that the steam mains and the hot-water returns, if any, will be as short as possible.

In the selection of the kiln site special care should be given to the suitable protection of the stock before it is loaded and after it is removed from the kilns. Dry stock should never be exposed to the weather; many plants find it a good investment to keep the stock which is to be dried under a roof. This plan is especially desirable in the case of green material, which is apt to check if exposed to the hot summer sun.

104. Layout of Battery of Kilns.—After the site of the kilns has been selected, careful thought must be given to the determination of the size and number of units and to their general

arrangement. Much of the success and satisfaction to be derived from the operation of kilns depends upon their layout.

(a) *Progressive Kilns*.—In progressive kilns less variation in arrangement is possible than in compartment kilns, since their design is less flexible. Progressive kilns must, because of their very nature, be double ended; that is, they must have a door at each end; the stock must be put in at one end, commonly called the green end, and pass through the entire kiln and out at the other, or dry, end. For economy of arrangement the entire battery should be in one group, side by side, since there must be facilities for loading or unloading at each end of each group, and since the individual kilns are usually comparatively long. The length of a progressive kiln is determined in a general way by the nature of the material being dried, as there must be a progression of drying conditions from end to end, and this progression must correspond to the needs of the stock. Almost all progressive kilns are 100 feet long or more.

The width of a cross-piled progressive kiln is, in general, slightly greater than the length of the stock to be dried. Progressive kilns are usually designed for lumber 16, 18, or 20 feet long, although in exceptional cases they are made much wider than these lengths. One kiln designed to dry ash refrigerator stock at a plant in Michigan is wide enough to take care of two rows of cars piled crosswise with 20-foot stock—about 45 feet. A Moore kiln used to dry cross-arm stock of Douglas fir is 46 feet wide inside and 216 feet long. There are many end-piled progressive kilns, with one or two tracks, in operation. The single-track kilns are usually about 11 to 12 feet wide and the double-track kilns 20 to 24 feet wide.

The height of the kilns, above the rails, is rather strictly limited by the height to which the trucks can be economically piled, and by various other considerations.

It is evident, therefore, that there is virtually no latitude to the size and the number of progressive kilns for any given drying conditions.

Logically, the green end of the kilns should be as near as possible to the source of supply of the green material, and the dry end as near as possible to the point of use or disposal. In a sawmill, for instance, the green end would be near the sorting chains or automatic stackers and the dry end near the planing mill, dry shed, or shipping platform, as the case may be.

In many progressive kilns the steam enters the heating coils at the green end of the kiln because it is more convenient to drain the coils toward the dry end, the rails being graded slightly in this direction to assist the movement of the trucks through the kilns. Sometimes there is an additional set of heating coils at the dry end, fed from a header near the center of the kiln. The drain header in many progressive kilns is at the dry end. These facts should be borne in mind in laying out the kilns, so that the steam may be supplied and the water removed with the least possible expense for piping.

(b) *Compartment Kilns*.—Since the layout of compartment kilns is much more flexible than that of progressive kilns, to secure the best results more thought and knowledge and more careful analysis are required.

Compartment kilns may be either single ended or double ended and of almost any desired length, within quite wide limits. For very exacting requirements, where only very small variations in temperature and humidity are permissible, it is customary to limit the length to about 40 or 50 feet. For less rigid requirements, lengths up to 110 feet are not uncommon.

The width of compartment kilns may be varied within comparatively definite limits, determined to a large extent by the nature of the material and the accuracy of drying required. The lumber in compartment kilns should almost invariably be end piled, since the circulation is usually crosswise. The stickers will then be parallel to the principal circulation, assisting it to take the desired path. It does not follow, however, that good drying cannot be accomplished in cross-circulation kilns with cross-piling. In fact, many kilns of this design are giving satisfaction under conditions where the lumber is dried easily.

Compartment kilns may be classed as single track or double track. In the former, there is one row of trucks, and in the latter there are two. The width of the truck loads, in flat-piled stock, is determined by the length of air travel allowed through the pile, for the particular class of stock being dried and the form of the pile. If there is a central flue or chimney in the pile, the pile can be somewhat more than twice as wide as when the air must travel across the entire width, as is the case with piles stacked solid, without flues. The length of air travel to secure the best results depends upon the stock and upon the kiln design. For rapid circulation, for slow-drying stock, and with drying

schedules permitting low humidities, the length of air travel may be comparatively long, possibly as long as 8 feet. For severe conditions, an air travel as short as 3 or 4 feet may be desirable or necessary. In edge stacking, the air travel through the pile is vertical and definitely limited by the height of the pile. In ordinary commercial practice the width of the pile or truck load, whether flat piled or edge stacked, usually varies from 6 to 10 feet, although occasionally much wider piles are used.

The height of the pile is limited, as in progressive kilns, by the height to which the trucks can be economically piled. Furthermore, uniform drying cannot be had with excessively high piles. The usual height of the pile above the rails is about 10 feet.

(c) *Size and Number of Kilns.*—It is evident that there is considerable latitude in the choice of the size of kiln for any particular condition. More consideration can, therefore, be given to the number and the grouping of the kilns to meet the individual plant requirements. It is obvious that the fewer the kilns the less will be the first cost, the less will be the attention required, but the less flexible will be the operation of the battery. The class of stock being dried, the plant needs, and the manner in which the stock is made available to the kilns will be the final determining factors. If various kinds of stock are to be dried simultaneously, especially if they require different drying schedules, or if the stock varies widely in moisture content or condition of seasoning, a large number of small kilns will be required. A schedule of the dry-stock requirements and of the drying time for each class of stock will show the kiln capacity and the number of kilns required, due regard being given to the limits on kiln size set by the drying requirements of the stock.

These drying requirements will largely govern the choice of the type of compartment kiln, as has been explained at the beginning of this chapter.

(d) *Grouping of Kilns.*—When the size and the number of kilns have been determined, the next step is to work out the best possible grouping into one or more units. Two general schemes of grouping are in common use.

1. The kilns in the entire battery may be arranged side by side in a single row.

2. They may be arranged in two rows facing each other, with loading and unloading facilities between.

Figure 96 illustrates the simplest possible grouping for progressive and compartment kilns. Several other grouping schemes are used in special instances, such as an arrangement in two or more tiers, one above the other. This arrangement is sometimes used when a large number of small units must be

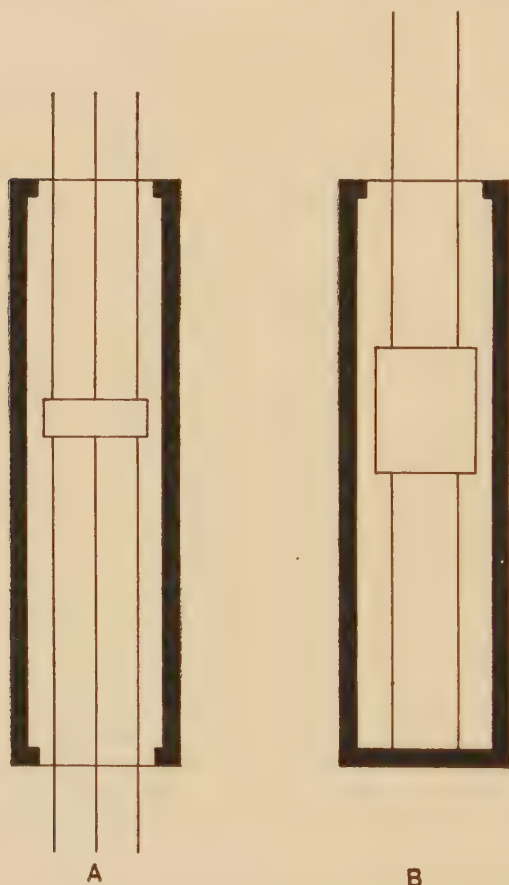


FIG. 96.—The simplest possible layout for progressive kilns, *A*, and compartment kilns, *B*, where the stock is handled on trucks. It is intended that the material to be dried be hauled to and from the kilns in wagons or trucks. Only enough outside trackage is shown to provide for one truck at a time.

placed on a very limited area. Special kinds of kilns, such as those used for spoke billets, present unique problems in layout, especially when some novel scheme of handling the stock is employed. Some of these kilns are fed through the roof, by

means of automatic hoppers or conveyors, and are unloaded through doors in the sides or ends.

The choice of the grouping to use depends upon the class of stock to be dried as well as upon the physical arrangement of the plant. Certain groupings seem to be more or less accepted in different branches of the lumber-manufacturing and wood-using industries.

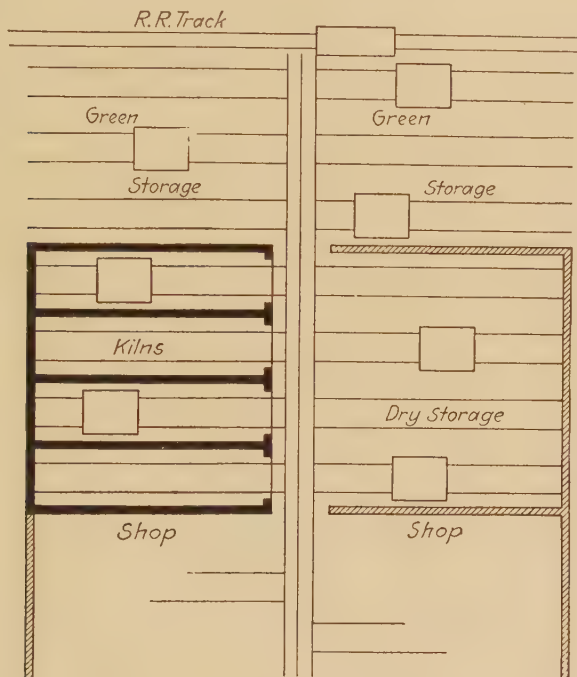


FIG. 97.—A typical compartment kiln layout for a factory.

The four kilns are end-piled, with single tracks. The dry storage is under cover, and the green storage is in the open. A transfer serves kilns, storage, both green and dry, and the shop. This layout would be satisfactory for a concern which purchases air-dry hardwoods and does not need any reserve storage capacity.

Large and small batteries of compartment kilns used for drying softwoods at the sawmill are almost invariably grouped in single rows, the kilns being usually of the double-ended type. A number of recent installations, especially on the Pacific Coast, are, however, of the single-end type, the claim being made that the extra time required for loading and unloading this type is more than balanced by the fact that only one transfer unit and one transfer crew are required to handle the lumber when it is

put into the kilns and when it is taken out. Small batteries of kilns at wood-using plants are also usually grouped in single rows and are liable to be double ended, although both styles are used extensively. Large batteries at wood-using plants are

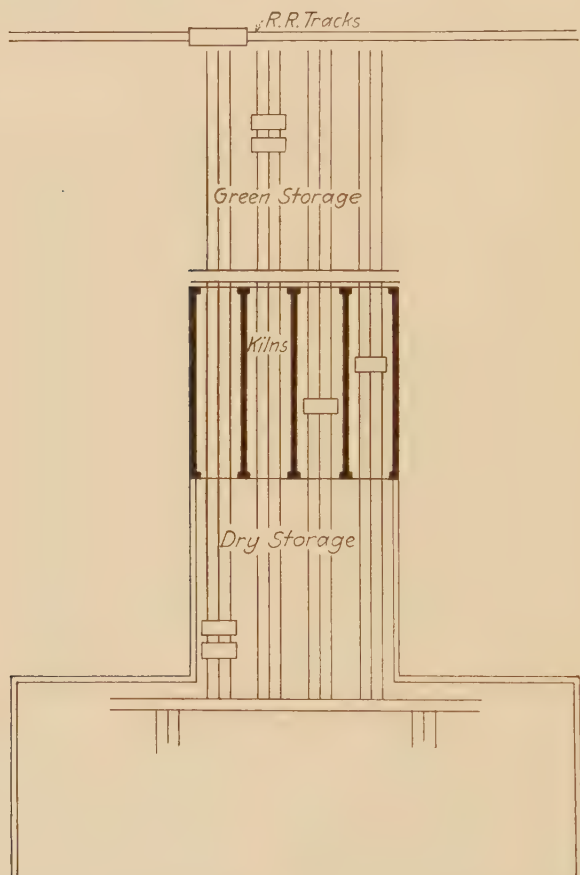


FIG. 98.—A typical progressive kiln layout for a factory.

The four kilns are cross-piled, with three rails each. Two transfers are required to serve the kilns, storage, and shop properly. This layout is intended for about the same kind of factory as that shown in Fig. 97.

The general arrangement of green storage, kilns, and dry storage can be adapted to double-end compartment kilns as well as to progressive kilns.

often arranged in two parallel rows, single ended, with loading and unloading facilities between them. In the better class of installations the space between the rows of kilns is covered with some type of monitor roof, and the ends are enclosed. This

makes an ideal arrangement, in that the working conditions are more pleasant; the kilns and apparatus are better protected; the lumber is sheltered from the sun, rain, and snow; and the heat losses from the doors are reduced. This idea is occasionally carried still further, and the entire battery of kilns housed in a building large enough to allow a passageway all around the kilns and provided with walls and roof entirely independent of the kilns themselves. Figures 97 and 98 show typical factory layouts for compartment and progressive kilns.

105. Storage, Loading, Unloading.—The kilns themselves form only a part of the equipment required to kiln dry lumber. Means must also be provided for the storage of green and dry stock and for loading and unloading the kilns. Requirements in this respect vary greatly; it is often difficult to determine the most economical arrangement for any given conditions. It is apparent that the kind of operation being carried on is a leading factor and that the space available is often the final determining factor. The amount of green stock to be carried must first be determined and then the amount of dry stock. The space required for each can then be calculated.

(a) *Time of Drying versus Type of Loading and Unloading Equipment.*—The time required for the drying process largely determines the size and the type of loading and unloading equipment; the more rapid the drying the more efficient must be the handling equipment and the larger must be the storage facilities at both ends. For instance, for heavy vehicle stock, gun stocks, shoe lasts, and other material which must remain in the kilns for two months or more, comparatively simple handling equipment is adequate. A number of installations designed for these classes of stock have no handling equipment whatever except wagons or possibly a standard-gage track for stock to be loaded direct from the car to the kiln. The stock is loaded and unloaded by hand; yard or shed storage is provided for the green stock, and the dry stock is used about as fast as it becomes available, or is stored in the factory. A small progressive unit drying previously air-dried stock for a certain specialized furniture factory using one kind and size of wood almost exclusively is almost as simple. The lumber is piled on trucks in front of the green end of the kiln. After it is passed through the kiln, it is delivered at the surfacer in the factory. The dry end of the kiln extends 20 or 30 feet into the factory building.

(b) *Equipment for Large Softwood Mills.*—Large softwood drying operations, in which the drying takes from thirty to seventy-two hours, and the lumber is delivered direct from the saw to the stackers and from the stackers to the kilns, require a large storage space for trucks of green lumber and also for trucks of dry lumber. The simplest way to arrange the trackage, with double-end kilns, is to extend the rails the full kiln length both

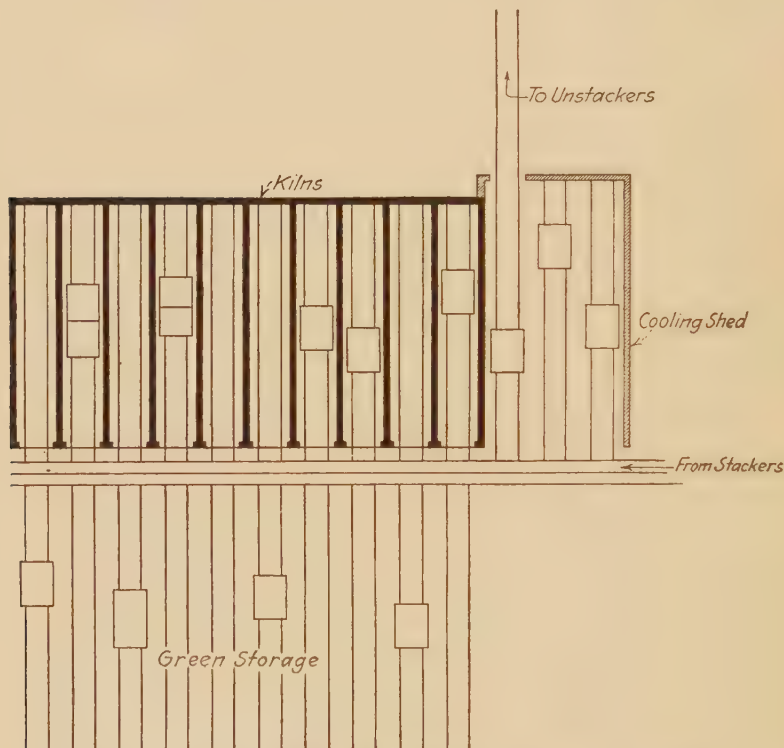


FIG. 99.—A typical single-end compartment kiln layout for a sawmill.

This arrangement is designed for edge-stacking, but it can be used for flat-piled stock as well. One power-driven transfer with winch and cable serves the entire battery. Note that the kilns must be unloaded a truck at a time but that an entire kiln charge may be loaded at one operation.

in front of and in back of the kilns. This allows a full kiln charge of green lumber to be stored in front of each kiln and a full charge of dry lumber to be drawn from the kiln and stored back of it. This scheme requires a large amount of track and space, but it provides for the quickest possible loading and unloading of the kilns.

A transfer must be provided at each end. The transfer car needs to be only wide enough for one truck load, but the tracks on which it runs must extend the full width of the battery and sufficiently further, if necessary, to reach the stackers or the unloading system. A much smaller amount of trackage will suffice if the kilns are progressive, since they are loaded with only a truck or two of lumber at a time.

In single-end compartment kilns, in large softwood operations, it is customary to locate the transfer tracks immediately in front of the kilns and to extend the tracks for the kiln trucks a full kiln length beyond the transfer. This arrangement makes it possible to hold a full kiln charge of green stock on the tracks in front of each kiln, but it does not provide space for any of the dry stock which is removed from the kiln. This must be run on the transfer a truck load at a time and switched to an unloading track. The amount of unloading trackage needed is much less than that provided for in the double-end kilns just discussed. Figure 99 illustrates an installation of this type.

(c) *Equipment for Hardwood Mills.*—Almost all hardwood-lumber drying operations do not require nearly so much trackage as do softwood operations of the same cubic capacity, because the drying time is much greater and the amount of stock handled daily is much smaller. Moving the trucks into the kiln and out again one at a time is usually perfectly satisfactory in hardwood-lumber drying; the piling and the unpling are always hand operations; and the amount of loading track need not be great. Usually, a trackage sufficient to hold one or two kiln loads of trucks is ample for the loading and green storage. Entirely apart from this is the keeping of all or part of the yard stock on kiln trucks, as is done at several model hardwood-using plants. The amount of this yard space depends upon the sources of supply and the manufacturing practice. It is not strictly a kiln matter.

Dry storage at the wood-using plant presents a problem different from that at the softwood sawmill. Here it is usually desirable to keep the dry stock on trucks until it is used in the factory. Provision should also be made for sufficient trackage to keep the supply of dry lumber of various kinds always ahead of the need of the factory.

(d) *Green and Dry Sheds.*—The present practice followed in protecting the stock before and after drying is not always satis-

factory. Green stock of both hardwoods and softwoods should be protected from the sun. Exposure to the sun for even a few hours on a hot day may cause surface checks to develop. The best way to prevent such a loss is to build a roof over the green storage tracks. If the stock has already been well air seasoned, the danger from checking on exposure will be much less.

Softwood lumber should be allowed to cool before it is machined, or even before it is unplied. Hot stock will dry too fast and check if exposed to the air and is very apt to split if roughly handled or machined before it is cooled. It is good practice (followed by many operators) to enclose the dry storage tracks, making a so-called cooling shed. The better this shed is made, and the tighter the enclosure, the better it will be for the lumber. After the lumber is cooled and conditioned, a day or longer if possible, it can be unplied and manufactured or stored in dry sheds as the circumstances may require.

For hardwoods, the dry-storage requirements are usually different, since the stock is intended for more or less immediate use and is to be held in a proper dry condition in the interim. The lumber can, and usually should, be cooled in the kiln and then placed in a dry-storage shed which is entirely enclosed and which may be heated sufficiently to keep the stock from reabsorbing moisture from the surrounding atmosphere. Storage for a week will allow the moisture in the wood to diffuse itself uniformly throughout and will eliminate factory troubles arising from uneven moisture distribution.

106. Kiln Construction. (*a*) *General Considerations.*—Many materials and many forms of construction have been used in the building of the various kinds of dry kilns. Experience has proved, however, that the number of practical building types is comparatively limited. At present four building materials are in common use: wood, concrete, brick, and terra-cotta tile. Steel of structural and other shapes is used to a limited extent in the kiln buildings themselves, and quite extensively for track and heating-coil support. The requirements for a satisfactory kiln building are quite exacting and must be well understood if the structure is to serve its purpose.

Besides having to withstand the weather as ordinary buildings must, kilns must also resist the action of high temperatures and high humidities inside, the expansion and contraction caused by frequent and wide changes in temperature, and frequently

also the corrosive action of acid vapors from the woods which are being dried. To be efficient, the kiln walls and the roof must be reasonably good heat insulators and reasonably impervious to water vapor. The best drying results are secured with ceilings which are practically flat—the material of which the roof is built must, of course, lend itself to this form of construction.

The two principal considerations in the selection of the materials of construction are usually the permanence of the operation and the cost of the type of construction which is suitable to the class of drying to be done. It is assumed that each of the four materials will prove satisfactory from the standpoint of operation if the design is properly worked out.

Foundations are almost always of concrete, regardless of what material is used for the walls and the roof, although occasionally wooden foundations, usually of pine or Douglas fir, are used. Wood is used for the walls and the roof when the operation is to be of short duration, ten years or less, and often for longer operations, especially at sawmills, where the difference in price is greatly in favor of wood construction. Many woods, such as pine, Douglas fir, spruce, cypress, and redwood, are satisfactory for kiln construction.

Just as the tendency toward "permanent" forms of construction in sawmill buildings is steadily increasing, so is the tendency to use brick, tile, or concrete in wall and roof construction of kilns, even at sawmills, steadily increasing. A number of mills using these materials for walls are, however, using wooden roofs in preference to the more expensive materials.

The individual peculiarities of the materials must be taken into consideration in their selection and use. The chief difficulty with wood, except possibly when it is used as a foundation material, is that it shrinks and swells materially with changes in moisture and will cause trouble in this respect unless proper allowance is made in the design. All wood used in kiln buildings should be dried to about 8 per cent moisture. Concrete, although an excellent foundation material, is low in heat-insulating properties and is apt to cause trouble in controlling the humidity in the kiln because of its porous nature. It is difficult, also, to repair cracks in concrete unless it is of the reinforced type. Hard-burned bricks make excellent walls. Common bricks are so porous that the inside surfaces must usually be given a coat of cement plaster and then a coat or two of kiln paint to prevent

excessive loss of humidity and heat. Hard-burned, dense terra-cotta tile is one of the best kiln-building materials available and is used in permanent kilns very extensively, for both walls and ceilings. Brick, concrete, and tile all expand appreciably with heat, so that provision must be made for expansion joints at proper intervals, to avoid damage to the structure.

(b) *Structural Details*.—Good architectural and engineering practice should always be followed in the design and erection of kilns, since they are subjected to more severe conditions than ordinary buildings, and since carelessness or “cheap” construction is much more disastrous. The following suggestions are intended to serve as a guide, but they should not be followed blindly without assurance, through calculation, that the sizes mentioned are adequate for the particular structure being designed.

(c) *Subfoundations*.—Since it is not always possible to secure a kiln site of firm soil or rock, it is necessary to provide suitable support for the buildings. Settling, with resultant misalignment and the formation of cracks, is much more serious in kilns than in many other types of construction and must be avoided at all costs. The misalignment throws the trackage system out of line, and the cracks cause loss of heat and difficulty in humidity control. When it is not possible to secure the proper bearing area for the support of the structure by the use of footings of reasonable size, recourse must be had to the use of piling driven to a sufficient depth to insure the required bearing without settlement. Reinforced concrete or wooden caps across the rows of piling form the foundation for the building and the track supports. A number of kiln installations with piling subfoundations have been erected at tidewater mills. This form of construction is also used where the kiln site is in a hollow and the kilns have to be elevated above the surface of the ground. As a rule, experience with heavy buildings in the vicinity of the kiln site will serve as a guide to the requirements.

(d) *Foundations*.—Foundations for the walls of kilns are almost invariably of concrete. It is customary to build the side walls of concrete up to the track level, even when other materials are used for the upper portions of these walls. The width of the footings or the form of the subfoundation is determined by the character of the soil; the thickness of the foundation walls by the construction of the walls and the roof. Foundation walls for wood con-

struction may be 8 or 10 inches thick. For concrete, brick, or tile construction they are usually 12 or 13 inches thick. They should then usually be of the same thickness as the walls above them. The concrete should be dense and well spaded, and waterproofed if the drainage is not good or for any reason there is danger of water entering. The top line of the foundation walls for the side walls is usually parallel to the rails, taking the same slope if there is any.

(e) *Floors*.—Almost all kilns are provided with concrete floors, usually 4 inches thick. Occasionally, dirt or sand floors are found which are satisfactory; a few kilns have wooden floors. The concrete floor is recommended for practically all conditions and is usually without reinforcement. Special forms of construction, however, must be used in some cases, such, for instance, as kilns supported on piling or trestles and elevated above the surrounding ground. While not absolutely essential in most cases, it is good policy to pitch the floors slightly toward one corner, so that any water may be drained off. A pitch of $\frac{1}{20}$ inch per foot should be sufficient.

107. Walls.—The walls must be strong enough to support the roof and do their share toward producing a safe and durable building. They must also be good heat insulators and resistant to the severe conditions inside the kilns. Of all the possible forms of construction, comparatively few have proved entirely satisfactory.

(a) *Wooden Walls*.—Two forms of wooden-wall construction are generally used. These are illustrated in Fig. 100. Crib construction has been used extensively at sawmills, where the first cost of the wood is comparatively low. Crib walls are usually 6 inches thick, made up of 2 by 6 joists surfaced on four sides and laid flat and spiked together solid. This produces a solid wooden wall of satisfactory strength and of excellent insulating properties if the stock is thoroughly dry, perfectly flat, and sufficiently well spiked to eliminate all cracks. Walls of this type are too often made of green or partly dry stock. The shrinkage resulting from the drying out when the kilns are in operation causes trouble, not only from cracks, but also from the distortion of the door frames, occasional misalignment of piping, leaks in the roof, and similar troubles.

If extra good insulation is required, or if the walls do develop cracks, the outside walls may be covered with two- or three-

ply ready roofing and sheathed with drop siding, rustic, or similar tongue-and-groove siding.

Studding and sheathing walls are more common in wood-using plants than crib walls. Properly constructed, they are very satisfactory structurally as well as from the standpoint of insulation.

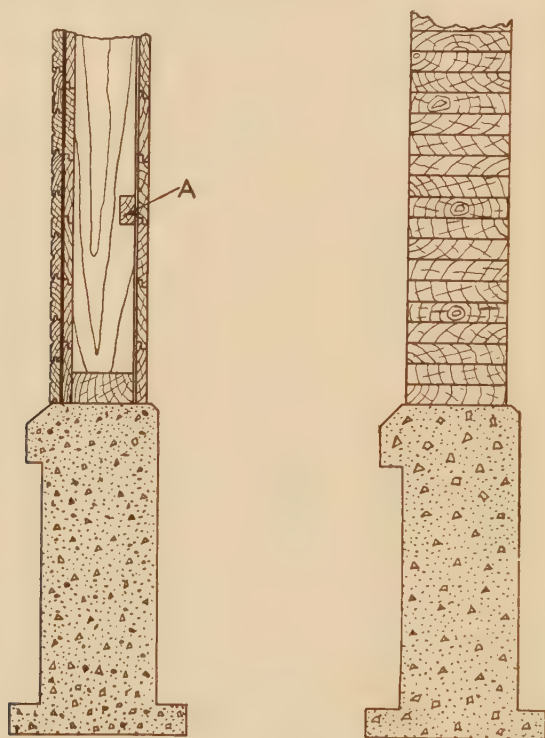


FIG. 100.—Two forms of wooden-wall construction.

The left section is an outside wall of studding, sheathing, and siding. On the outside is a layer of siding and one of sheathing, with ready roofing between. On the inside is a single layer of sheathing and a layer of ready roofing. A row of battens, *A*, along the seams between the courses of ready roofing helps to make a good job. The right section is of crib construction, the layers being firmly spiked together.

Walls of this type are usually constructed of 2 by 6 studs on 16-inch centers, with 1-inch single or double sheathing on both sides. Where differences in temperature between adjacent kilns are not great and accurate control of the drying conditions is not essential, partition walls with single sheathing on each side are satisfactory. Likewise, under similar conditions and where comparatively low kiln temperatures are used, outside walls with a single layer of sheathing on the inside and a double

layer on the outside will suffice. For more exacting work, double sheathing should be used on both sides. Inside sheathing is usually of shiplap or of a dressed and matched pattern, laid horizontally. Outside sheathing on outside walls may be of any dressed and matched siding. All sheathing exposed to kiln conditions should be nailed so that a slight shrinkage and swelling may take place. This may be accomplished by using two nails in each stud, one at the center and one at the bottom of each board.

To insure good insulation, it is necessary to use ready roofing on both sides of each wall. With single sheathing, the roofing is placed between the studding and the sheathing; with double sheathing, it is placed between the two layers. Insulating quilts are occasionally used, but they are apt to become wet during steaming periods, when their efficiency becomes very low. With single sheathing, it is excellent practice to use horizontal rows of stops or nailing strips between the studs on a line with the joints or laps in the roofing. This will increase its efficiency as an insulator very materially.

(b) *Concrete Walls.*—Although concrete is almost invariably used for foundations and floors, it is not often used for either partitions or outside walls. The necessity for forms in pouring the concrete makes the construction expensive; the insulating properties of average concrete are not very good; the finished wall is heavy; and provision must be made for contraction upon setting and for expansion when the kilns are warmed up. In spite of these drawbacks, however, there are occasions when it is the proper material to use, as, for instance, when gravel and sand are available at little or no cost, and the work can be done by the company's own men without added supervision costs. Partition walls as thin as 6 inches are apparently successful, but it is usually better to make them 8 or 10 inches thick and to make the outside walls 12 inches thick. A better construction for outside walls is an 8-inch concrete wall with a 4-inch lining of dense tile on the inside. Reinforced-concrete pilasters at intervals of about 20 feet will increase the stiffness and general serviceability of the walls very materially. Their use is especially recommended for thin walls.

To secure the best results from concrete, the walls should be as dense as possible, the aggregate being graded as is customary in waterproofing where the denseness is principally relied upon

to produce the waterproof quality. The finished walls should, of course, be painted.

To provide for expansion and contraction a vertical expansion joint at least $\frac{1}{2}$ inch wide should be built in every 40 or 50 feet. If pilasters are used, a joint should be made at each side of every other pilaster. Of the several types of expansion joints commonly used in concrete construction, the tongue-and-groove type is best adapted to kiln construction. A vertical groove about 4 inches deep and as wide as the wall should be formed in the pilaster, which is cast first. A strip of saturated felt $\frac{1}{2}$ inch thick and of the width of the groove is then fastened to the bottom of the groove, and the sides of the groove smeared with soap or axle grease to prevent the fresh concrete from adhering. When the wall is cast, it fits the groove and can contract and expand without danger to the structure.

(c) *Brick Walls*.—To be satisfactory, brick walls should be made of dense, hard brick laid up in cement mortar, or in cement mortar tempered with lime. The strongest wall will result if neat cement mortar is used, but this is generally considered impracticable. Even a cement-and-sand mortar is comparatively difficult to work, being very "short," and for this reason is usually tempered.

Brick partition walls are usually 9 inches thick, with the ordinary English bond. Outside walls are usually 13 inches thick.

Suitable copings should be provided on the tops of all exposed brick walls to keep the rain from seeping through. Probably the most satisfactory coping is glazed tile. Cement copings are also used, and sometimes a row of bricks set on edge and laid in neat cement mortar with full joints. Double brick walls, with an air space between them, are not recommended for ordinary work.

Brick walls, if built of suitable brick, can usually be made sufficiently impervious by means of paint.

(d) *Terra-cotta Tile Walls*.—Terra cotta is well adapted to kiln-wall construction and is used in a large percentage of first-class jobs. Typical tile walls are shown in Fig. 101. The tile should be of the dense or hard-burned variety and should contain a comparatively large number of small cells so that the insulating properties may be of the best. To secure the most effective insulation, the tile should be laid with the cells horizontal. A

structure with greater resistance to vertical loads will be secured, however, if the wall is laid with the cells vertical. A compromise may be effected by placing most of the tile with the cells vertical and occasionally breaking up the flues formed by the rows of vertical cells by putting in one tile with the cells

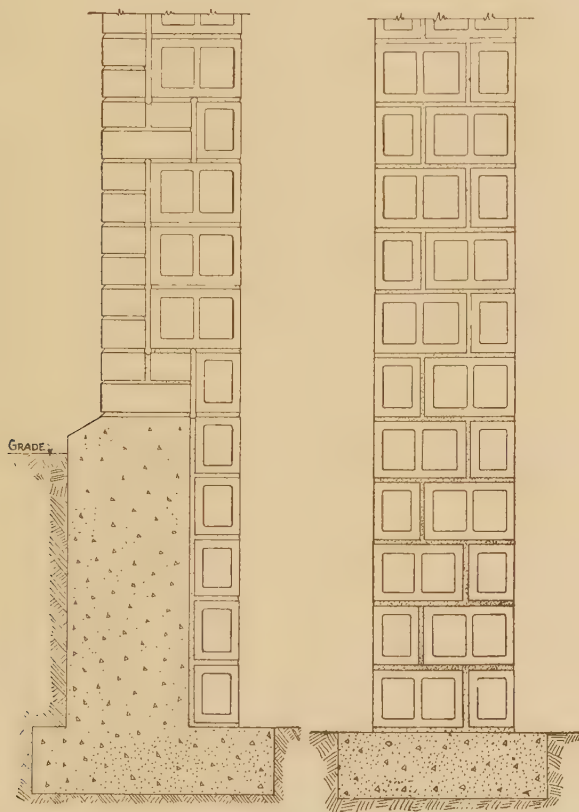


FIG. 101.—Typical tile kiln walls.

The left section represents an outside wall, with concrete up to grade and brick face. The other section represents a partition wall. "Bakup" tile is shown in both.

horizontal. A header row of bricks or of special kiln tile put in occasionally is still better.

Partition walls are usually 8 or 12 inches thick, preferably 12; the outside walls are almost always 12 inches thick. Frequently, the outside walls are made up with 8-inch tile and a 4-inch face brick veneer. When no face veneer is used, the outer surface of

the tile is left exposed or else stuccoed. Sometimes partition walls are plastered with cement plaster to increase their imperviousness, but this is usually considered unnecessary, paint being used instead. Surfaces which are to be plastered or stuccoed should be scored; those which are to be painted should be left smooth. Tempered mortar should be used, just as in building brick walls, and the joints should be full and flush.

It is customary to strengthen tile kiln walls with reinforced-concrete pilasters at intervals of about 20 feet, and to make a tongue-and-groove expansion joint on each side of each pilaster. The grooves in the pilasters need not be over 2 inches deep, and the tile may project $1\frac{1}{2}$ inches into the groove. The $\frac{1}{2}$ -inch clearance space should be kept free from mortar. This method provides more room for expansion than is really needed and is recommended largely on account of the excellent joint secured between the tile and the pilaster.

A grade of tile called "load-bearing," especially adapted for wall construction, where the weight of the roof is supported on the wall, is available. The 12- by 12- by 12-inch size is reported to be the most popular for kiln walls. A special kiln-wall tile, known as "bakup," is made in two sizes, 4 by 5 by 12 inches and 8 by 5 by 12 inches, three sides being scored for mortar or plaster. Both are intended to be laid with the cells horizontal. The 4-inch wide tile has one cell, and the 8-inch, two, with a vertical partition. Twelve-inch walls are made by laying an 8- and a 4-inch tile side by side, staggering the joints in successive courses.

108. Roof and Ceiling.—To give thorough satisfaction, the kiln roof must fulfil a number of exacting requirements: It must be structurally sound; it must be weatherproof; it must be a good heat insulator; it must be nearly flat on the under or ceiling side to keep the distance between the lumber and the ceiling as nearly constant as possible; the top surface must have enough pitch or slope to drain off rain water and melted snow; and the whole structure must be durable.

Almost all kiln roofs are built so that both the under and the upper surfaces are practically flat, with a slight pitch. Occasionally, it is found expedient to make the ceiling and roof separate, with an appreciable space or attic between them. If this is done, the pitch of the roof may be made great enough to permit the use of almost any desired roof covering, and the ceiling can be

constructed to provide the necessary insulation and tightness. These double-roof and ceiling constructions are usually made of wood.

In general, except in the double construction mentioned, the flatness of the roof demands the use of the type of roofing commonly known as "composition" or "tar and gravel," of which there are various kinds and qualities. If properly constructed, these roofings will give satisfactory service with a roof pitch as low as $\frac{1}{8}$ inch per foot and as high as 3 inches per foot, without any special provision for nailing the felts to the roof.

It is customary, in kiln roofs, to provide a pitch ranging from $\frac{1}{4}$ to $\frac{1}{2}$ inch per foot. This pitch is sometimes exceeded, especially in wood-joist roofs, with cheap ready roofing. In progressive kilns, the pitch is usually downward toward the dry end, since the rails pitch that way, and in compartment kilns it is usually crosswise, except possibly in a large battery of very short kilns, or in double-ended kilns with pitched tracks. In a battery of fairly long single-ended compartment kilns, the roof pitch is usually to the right for one or two kilns and then to the left. A slight pitch to the front or to the rear at the low points of the roof will help the water to flow to the down-spouts.

Composition roofs for kilns are usually of three- to five-ply roofing felt or three-ply asbestos roofing felt, laid in accordance with various specifications. The well-known Barrett specification is a guarantee of a first-class tar-and-gravel roof. Almost all specifications provide for suitable flashing and counterflashing around the walls. Suitable grooves and means for fastening the flashing and counterflashing must be provided when the walls are erected.

(a) *Wooden Roofs.*—There are two kinds of wooden roofs in general use, just as there are two kinds of wooden walls. The crib roof has proved popular for sawmills and is used quite extensively on kilns with brick or tile walls as well as in all-wood construction. Crib roofs are built just like crib walls, usually out of 2 by 6 or 2 by 8 low-grade stock, laid on edge, and spiked firmly together. Sometimes they are not even covered with a composition roofing. A three- or four-ply composition roof is, however, recommended. The wood should be thoroughly dry, preferably down to 8 per cent moisture.

Joist roofs are, for ordinary spans of 16 to 20 feet, usually made of 2- by 10-inch yellow pine or Douglas fir joists spaced 16

inches on centers, or of 2- by 12-inch joists spaced 24 inches on centers. One row of bridging is usually specified.

Sheathing and ready roofing are used for roofs in a manner similar to that for walls. Sometimes 2-inch sheathing is used immediately on top of the joists instead of the 1-inch usually used on walls. Since poor insulation causes more trouble with roofs

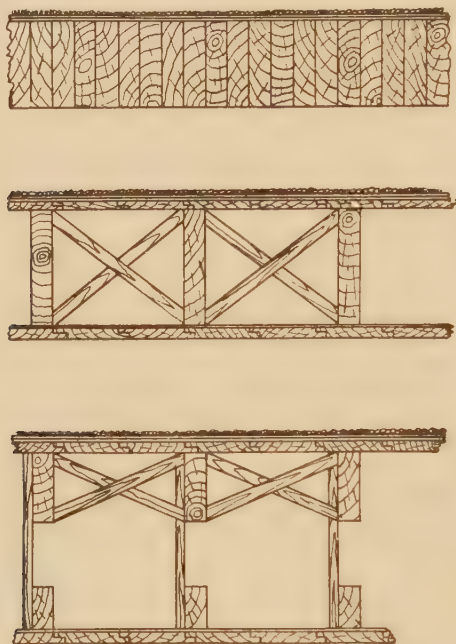


FIG. 102.—Typical wooden roof construction.

The upper section is of crib construction. The center one is of standard joist construction, with sheathing above and below. There is also a layer of ready roofing directly above the lower layer of sheathing. The lower section represents a drop-ceiling construction, in which the ceiling is hung from the roof by battens. A single layer of ready roofing is used. This form of construction is especially adaptable to sloping roofs where a horizontal ceiling is desired.

Some form of composition or ready roofing should be put on over the upper sheathing, though sometimes the crib roofs are left without any protection against rain.

than with walls, largely on account of condensation, it is generally considered good practice to use a double sheathing top and bottom, with ready roofing between. A three- or four-ply composition roof should be specified. Three types of wooden roof are illustrated in Fig. 102.

(b) *Reinforced-concrete Roofs*.—Slab roofs of reinforced concrete are occasionally used where they can be constructed economically. They are not recommended for general use, however, for the

reasons enumerated in the discussion on concrete walls. The thickness and general design of the slab should be such that it will be structurally safe, with special provision made for insulation. Insulation may be in the nature of a cinder fill 4 to 6 inches thick, covered with a 1-inch cement grout, or it may consist of a 4-inch layer of terra-cotta tile. Occasionally, it may be desirable to use a false ceiling under the slab roof. Several roofs have recently been insulated with a layer of cork from 1 to 3 inches thick laid on the top of the slab and mopped on with pitch. Celotex has also been used for this purpose. As yet no data on its serviceability are available; but if it can be kept dry, it should serve very well. A composition roof, preferably five-ply, should be used on top of these various forms of construction.

The concrete in the slab should be "dense" to make it as impervious as possible, and it is excellent practice to reinforce the slab

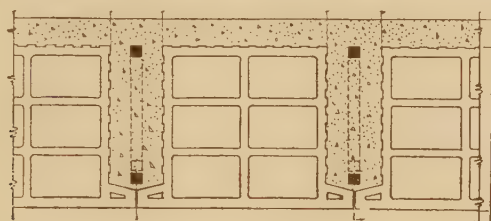


FIG. 103.—A section of a tile and concrete roof.

Standard lip tile, made especially for the purpose, are generally used. Space is provided for the reinforced-concrete beams between the rows of tile, and a concrete slab covers the whole. A tar and gravel roof is usually laid over the slab.

in both directions on account of the expansion and contraction. Expansion joints should be provided at least every 50 feet, and closer if practicable. They should be at least $\frac{1}{2}$ inch wide, filled with saturated felt, and located over walls whenever possible. The roofing is usually laid directly over the joints, when they are not incorporated in the walls, although occasionally expansion flashing is specified.

If a cinder fill is used as an insulator, the top of the slab should be given a heavy coat of pitch to assist in preventing the penetration of vapor into the cinders. Sometimes the cinder fill is graduated in thickness from side to side if the slab is cast perfectly horizontal. This is done to secure the proper roof pitch.

(c) *Terra-cotta Tile Roofs*.—Flat roofs of dense terra-cotta tile with reinforced-concrete beams and a concrete slab are the most popular and the best of the "permanent" types. A roof

of this type is shown in Fig. 103. For the ordinary spans of from 16 to 20 feet, it is a common practice to use tile 12 inches deep, largely on account of the better insulation secured, even though this thickness may not be necessary from the standpoint of strength. Tile 6 or 8 inches deep are sometimes used, especially if additional insulation is provided by means of cinder fill, cork, or false ceiling.

Several forms of tile are used; the most popular and probably the best is the 12- by 16-inch, six-cell lip tile. The lip provides protection to the bottom of the concrete beam and increases the imperviousness and insulation of the roof. Occasionally, plain rectangular tile are used with no protection to the bottom of the beam. This difficulty may be overcome, however, if a special solid tile about 1 inch thick and as wide as the beam is laid between the large tiles, to form the bottom of the beam. The beams are usually about 4 inches wide. Various forms of reinforcing are used. It is customary to use one $\frac{5}{8}$ -inch square rod or its equivalent, bent to follow the tension side of the beam. Additional reinforcement may also be used, such as the shear reinforcement of the Kahn bar or an extra bar near the top of the beam wired to the lower bar.

Sometimes light reinforcement is used in the slab, running at right angles to the beams, or in the form of a mesh. Individual conditions, of course, determine the details of each design.

The thickness of the slab is usually uniform, generally 2 inches; sometimes it is $2\frac{1}{2}$ inches, rarely 3 inches. Occasionally, it is tapered or graduated to provide the proper roof pitch when the ceiling is horizontal.

Expansion joints at least $\frac{1}{2}$ inch in width should be provided every 50 feet. These can often be incorporated into the joint between the wall and the roof, and then left open; or they may be filled with asphalt or pitch.

A first-class composition roofing should be put on all tile roofs—the roofing should last as long as the rest of the structure.

(d) *False Ceilings*.—Almost all commercial kilns are so constructed that the under-side of the roof is at the proper height above the rails or floor throughout the length of the kiln. Sometimes, however, especially in remodeling work, it is necessary to put in a false ceiling, possibly a foot or more below the roof proper. While there are many possible ways in which false ceilings may be constructed, a simple wooden type will usually

be found ample. It may be constructed like one side of a wooden wall, with one or two layers of sheathing and ready roofing. One layer of sheathing will usually suffice, and 2- by 6-inch or even 2- by 4-inch joints spaced on 16-inch centers will be strong enough, especially if they are tied to the roof with 1 by 4 ribbons at the center or third points.

(e) *Ceiling Insulation*.—When the humidity of the atmosphere in the kiln is high—and it should be high for almost all classes of drying—trouble is apt to be caused by ceiling condensation, which drips on the lumber and also makes the control of the humidity difficult. This point is receiving attention from dry-kiln engineers, who are approaching it from two angles, namely, better roof insulation and special ceiling heating.

The trouble lies, of course, in the fact that the ceiling loses heat to the outside atmosphere and is much cooler than the inside of the kiln. If this radiation can be stopped, or if the heat loss can be supplied from some separate source, the air in the kiln will not be robbed of its heat, with a consequent drop in temperature and the resultant condensation.

Several insulating materials, such as cork and fibrous insulating boards, have been used to some extent, and they have apparently given good satisfaction. The Forest Products Laboratory has used cork insulation in a number of places in the experimental kilns and has secured very good results where the cork has been protected from the kiln atmosphere. A $\frac{1}{2}$ -inch layer of cork should be ample for almost all conditions. It can be used to the best advantage on the top of a concrete roof slab, to which it should be thoroughly mopped with pitch, to exclude vapor from the kiln. The composition roof can then be mopped to the cork.

The commonest way of avoiding condensation is by the use of a set of ceiling coils. These are usually of 1- or $1\frac{1}{4}$ -inch pipe, spaced about 2 feet apart along the ceiling. They can be made up into almost any kind of flat coil which will allow for expansion and drainage. These pipes should be fed direct from the steam main, independent of the main heating coils, and should be trapped separately so that they may be operated continuously. The *usual* practice is to suspend the ceiling coils directly beneath the ceiling, but the *logical* place for them is *above* the ceiling. They can sometimes be placed in the space between the false ceiling and the roof, which is an ideal location. A small vent

should be supplied for this space so that it may be dried out in case of accident.

109. Chimneys.—Chimneys or flues for the escape of moisture-laden air, of a form of construction to match the rest of the kiln, are provided in almost all kinds of natural-draft ventilated kilns. These flues are, in general, built in the walls or in pilasters, as the case may be. Special flue tile may be used, except for wooden construction. Where the tile projects above the kiln, it may be surrounded by a 4-inch brick-chimney construction, with a concrete slab on top.

110. Track Supports.—There are two standard ways in which the kiln track may be supported: (1) by posts directly beneath the rails; and (2) by beams resting on the foundation walls. These are shown in Fig. 104. The cost and the convenience usually determine the method to use in any given case. For double-track kilns, posts under the rails are almost invariably used. For narrow kilns, beams are often preferable, since they need no special footings and leave the floor of the kiln free for heating coils, spray lines, air ducts, and other necessary equipment. Furthermore, they require no special bracing as do almost all systems using post supports. Such bracing is required with the post supports to prevent the entire system from collapsing longitudinally when the trucks are pushed in or out, and to keep the gage of the rails correct and the track parallel with the walls. The supports for the heating pipes usually furnish the necessary lateral stability, being tied into the walls, but sometimes the broad base of the post is relied upon; two or three sets of diagonal braces under the rails provide against longitudinal thrust. Almost all kiln manufacturers have developed standard systems of support, with standard forms of posts and fastenings for the rails and bracing. One company has even devised a system with a uniform increase in the height of the posts from end to end of the kilns, intended for use where the floor of the kiln is level and the rails are pitched or inclined. Proper provision must be made for the expansion and contraction of the rails.

The kiln track is level or it is pitched to make the movement of the trucks easier. Single-end kilns almost invariably have level tracks. Double-end kilns, on the other hand, usually have pitched tracks. The amount of pitch depends upon the method of handling and the type of equipment used. A grade of $\frac{1}{2}$

per cent, that is, a drop of 6 inches per 100 feet, is about the minimum, and is used where ample power is available for hauling the trucks. Where the trucks must be moved by hand, a steeper grade will be found advantageous—say 1 per cent, or 1 foot in 100. Even steeper grades than this are used, but they

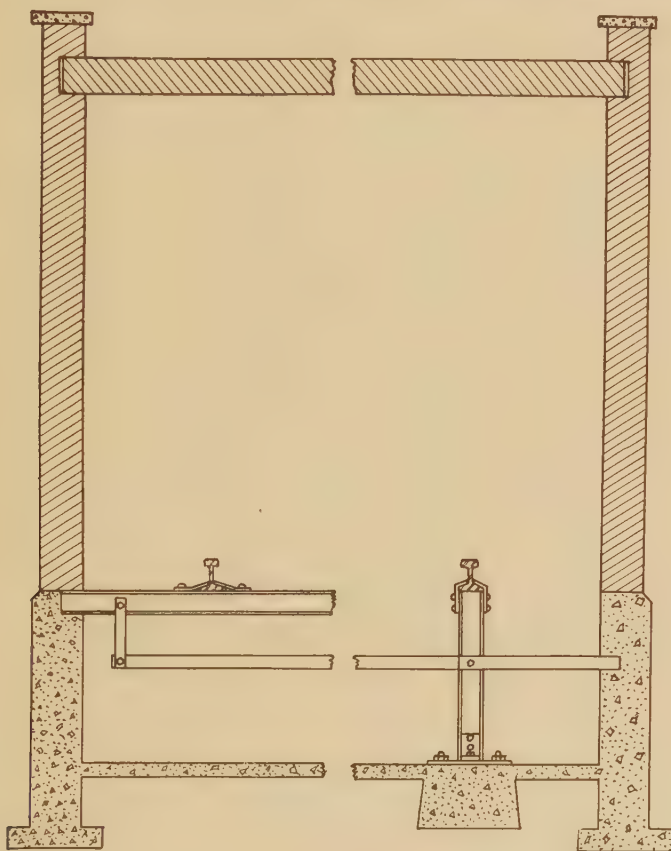


FIG. 104.—Kiln cross section, showing systems of supporting rails.

The two systems shown are in common use. The one shown at the left is preferred for wide kilns, and the other one for narrow kilns. In the former, special provision must be made for longitudinal bracing of the rails, to prevent collapse when a load is suddenly stopped on the track.

are apt to cause many accidents unless special care and special means are used to prevent the trucks from running away.

111. Doors.—The door is the weakest and the most unsatisfactory part of the average kiln, and it is the most difficult to improve upon. The structural difficulties in making a strong,

light, tight door, easily handled, of high insulating properties, and capable of resisting the corrosive action of the kiln atmosphere are great. The cost of a door meeting all these requirements would also be great.

(a) *Canvas Doors*.—A number of door types have been developed. Possibly the earliest to be used in large quantity



FIG. 105.—A slatted kiln door.

A popular form of construction. The door is built up of three layers of wood and two layers of 3-ply ready roofing or similar material. The central layer of wood consists of a frame of rails and stiles, as shown in the upper left corner. Each outer layer of wood consists of a frame of somewhat narrower material than that in the central layer, and vertical slats or battens. The lower left-hand corner shows the central layer and the outer frame. The lower right-hand corner shows how the ready roofing is tacked to the central frame, and the upper right-hand corner shows the finished door. This type of door is light and has good insulating properties.

was the canvas door, of the single or double type. The canvas door was used a great deal until a few years ago, but it has been largely displaced by other types. Canvas doors are easy to handle and cheap to install, but they are very poor insulators. Each door usually consists of two separate curtains, about a foot apart, each one of which may be rolled up independent of the other. At each side of each curtain there is a slot about 4 inches deep, into which the edge of the curtain fits. The batten

forming the front of the slot is hinged so that it may be swung forward out of the way when the curtain is to be rolled up. The life of the curtains is apt to be short at best, but it can be lengthened, especially for low-temperature work where mold is liable

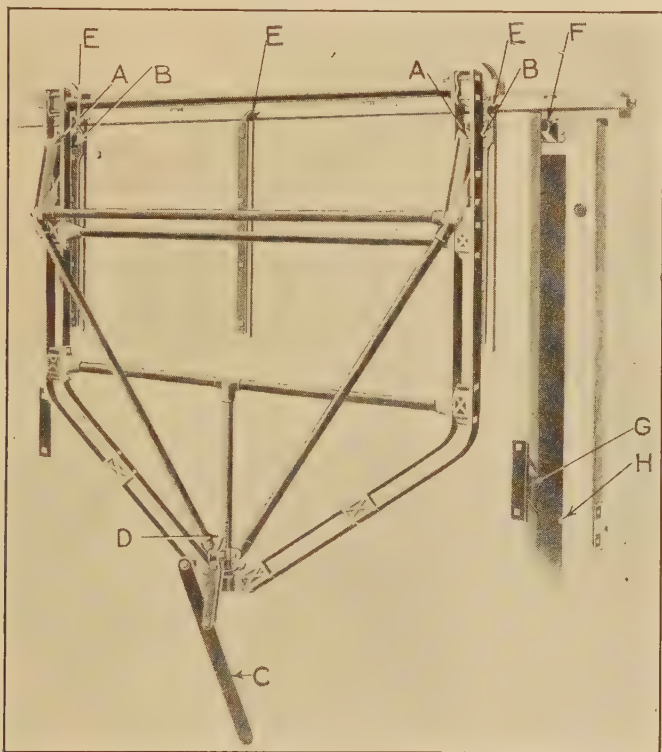


FIG. 106.—A dry-kiln door carrier. (Courtesy, Dry Kiln Door Carrier Co.)

The purpose of this device is to handle dry-kiln doors. The door is picked up bodily by the carrier and slid to one side upon rails. It may be left on the carrier or it may be set down and the carrier used for some other door. When the door is replaced, it is supported upon special fittings which are arranged so that the weight of the door serves to make a tight joint between the door and the frame. When the door is to be removed, the carrier is rolled in front of it. The pawls at *A* are engaged with the slots at *B*; pulling down on the lever *C* then lifts the door upward and outward. The pawl and ratchet *D* keep the door in its depressed position. The door may then be rolled either to the right or to the left. When the door is returned to its place, the three lugs *E* fit into their corresponding sockets *F*, only one of which is shown. These sockets are inclined downward and inward just as the socket *G* which fits over the stud *H*. The door is thus guided downward and inward, sliding on the guides until it is pressed firmly against the frame.

to occur, by painting both sides of the canvas with creosote thinned with kerosene.

(b) *Wooden Doors*.—Wooden doors of various kinds, made to slide up and down and provided with counterweights, were used

a number of years ago. Their use is now forbidden by several state industrial commissions on account of the danger of their falling, because of the breakage of the counterweight cables.

(c) *Wooden-slat Doors.*—The most popular door at present is undoubtedly the wooden-slat door. It is usually mounted upon the patent hanger of the Dry Kiln Door Carrier Co., although sometimes it is hinged or swung on rollers. This door is illustrated in Fig. 105. It embodies almost all of the desirable features of a good door, but it is not perfect enough to be considered ideal. It is comparatively light, reasonably

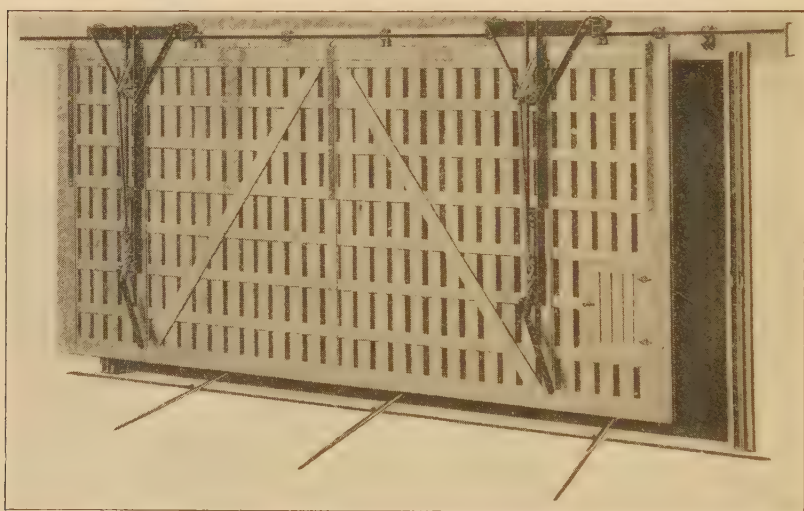


FIG. 107.—Double dry-kiln door carriers used on wide doors. (Courtesy, Dry Kiln Door Carrier Co.)

The principle of operation is the same as that of the single carrier shown in Fig. 106. The illustration shows a slatted door with a small inspection door to enable the operator to enter the kiln without opening the large door. Slatted doors are more commonly used with the dry-kiln door carriers than any other type.

cheap, comparatively easy to handle, takes up practically no room, can be made to fit reasonably well, and is probably as good an insulator as can be expected in view of the rest of its good qualities. It must be remembered, however, that the door is only 3 inches thick, compared with the walls and the roof, which are probably 12 inches thick. Figures 106 and 107 show the single- and double-door carrier.

The slat door is usually constructed as follows: Three layers of wood and two layers of ready roofing are used. The central

layer of wood is simply a frame of stiles and battens, about $\frac{7}{8}$ inch thick, dovetailed or suitably braced. Over each side of this frame is stretched a layer of three-ply ready roofing, firmly tacked with copper tacks; $\frac{3}{8}$ - by 4-inch vertical strips are then fastened over each layer of roofing, spaced about $\frac{1}{4}$ to $\frac{1}{2}$ inch apart the full width of the door, except at the edges, where the strips are usually heavier. Heavy strips are also nailed across the top and the bottom. Diagonal braces are often added, especially in wide doors. The fastenings should always be of brass or copper, and the wooden parts should be painted with two coats of asphalt or kiln paint before they are fastened together. If the door is to be operated by the door carrier, special hangers must be fastened to the top of the door and special fixtures to the sides. Special fixtures must also be fitted to the door jamb. When the door is released from the carrier, it slides downward and inward for several inches on the special fittings until it seats itself firmly by its own weight, against the door frame.

(d) *Iron Frame and Cork Doors*.—A first-class door can be made out of angle-iron frame and sheet cork, with an inner facing of sheet iron. The cork may be $\frac{1}{2}$ inch thick or more. This door is rather heavy, but it will give excellent service if the iron facing is kept well painted. No kind of iron is entirely satisfactory for this purpose, but it is probable that ingot iron should be used. Copper would do very well, but it is quite expensive.

(e) *Three-ply Wooden Doors*.—A three-ply wooden door, made of thoroughly dry 1- by 4-inch battens, surfaced to $\frac{5}{8}$ or $\frac{3}{4}$ inch, and sheathed with iron all around, makes a durable door of excellent insulating properties and permanence of form if the iron is kept painted. The battens in the adjacent layers should be at an angle to each other. This form of construction is too heavy for a carrier.

(f) *Hinged Doors*.—Hinged doors have not been developed to nearly so great an extent as their excellence warrants, probably because a poor hinged door is an abomination. A first-class, well-made hinged door has much to recommend it. If the frame is made heavy and rigid enough to support the door properly, it is possible to produce excellent results in the matter of insulation and ease of operation. The door can be made heavy enough to give the required rigidity and insulation, and heavy clamps can be fitted to draw it snug against the door frame.

Hinged doors are either single or double, according to the width of the opening and the amount of clearance available for opening them. Assuming a battery of kilns, with a transfer across the front, it is obvious that, if adjacent kilns are to be open at the same time, a platform at least as wide as the doors must be provided so that the transfer car may clear the open doors. The single door avoids the somewhat difficult joint between the halves of a double door, but requires heavier hinges and more rigid construction.

To make a tight joint between the door and the frame, felts are usually fitted to them. These felts, either bare or canvas-bound, are not very durable, and must be replaced at intervals. Special provision must be made to insure a tight fit at the bottom of the door, and some special form of adjustment should be provided on the hinges to take up any looseness on the hinge edge of the door.

(g) *Inspection Doors*.—Small doors should be provided on each kiln so that the operator may enter and leave without difficulty while the kiln is in operation. These doors are often fitted into the main doors if no other space is available. They should always be provided with latches which can be operated from the inside of the kiln.

112. Painting.—The kiln atmosphere has a corrosive effect upon the ironwork and is destructive to lime mortar. Because painting overcomes these disadvantages, decreases heat losses, and assists in controlling the humidity, it is recommended that all of the interior of all kilns be kept painted with a first-class kiln paint.

113. Insurance.—Before the plans for kilns are finally approved, consideration should be given to the matter of fire insurance. Various underwriters have special stipulations upon which rates are based. Among these are the distance from other risks, type of construction used, and means of fighting fire, such as location of fire hydrants and extinguishers. Many kilns are provided with automatic sprinklers, when the rest of the plant is equipped with them, and sometimes special steam lines opening directly into the kilns are installed so that the kilns may be filled with steam in case of fire. The steam-jet lines fitted to many kilns may serve this same purpose.

CHAPTER X

THE OPERATION OF A DRY KILN

114. Importance of Careful Kiln Operation.—In this chapter instructions are given for the drying of lumber in a kiln from the start to the finish. However, these instructions cover the operation of a kiln only in a general way, it being impracticable in a text of this kind to go into many of the details and exceptions that an operator becomes familiar with in practice.

The success of the operator, furthermore, will depend to a great extent on his intelligence and power of observation. There is no automatic method of drying lumber which requires only placing the lumber in the kiln and removing it after a given time, like baking a potato in an oven. The operation of a kiln requires the careful, intelligent attention of one who is familiar with the behavior of wood under various conditions of temperature and humidity. In other words, instead of a "cut-and-dry" procedure, intelligent kiln operation becomes a "cut-and-try" method. The motto of a dry-kiln operator should be "Watch the Stock!" He should be familiar enough with making critical examinations of the lumber and with making tests so that he can detect anything that is going wrong in the kiln. He should then be able to make adjustments accordingly.

Some of the directions given may appear more detailed or technical than is necessary, but it should be remembered that the instructions apply particularly to stock which is difficult to dry, as thick green hardwoods, and to stock which must meet exacting requirements, such as that used for furniture and other high-class work in which joints, mortises, laminated construction, resawing, and shaping are involved. For this class of work the material must not only be free from such obvious defects as checks, honeycomb, warp, etc. but must also be free from brittleness, internal stresses, and uneven moisture content. For less exacting work somewhat less accurate methods may be consistent with efficient production.

115. Instruments Recommended.—To run a dry kiln properly an operator should be equipped with certain instruments with which he can make accurate observations instead of relying on rule-of-thumb methods. The following instruments and accessories are recommended:

One sensitive balance (capacity 0.1 to 1,000 grams).

One drying oven in which the air can be heated to and held at temperatures between 200 and 212°F. Heat may be supplied by electricity, boiling water, or steam.

Three to six accurate standardized ordinary glass thermometers with engraved stems (60 to 230°F., by 2° intervals).

Three accurate standardized maximum glass thermometers with engraved stems (60 to 230°F., by 2° intervals).

One accurate standardized wet-and-dry-bulb hygrometer (60 to 230°F., by 2° intervals) for each kiln and three or four extras, and enough extra wicks to provide for changing the wicks once a week for a period of several months. These and the above-mentioned apparatus may be obtained from laboratory-supply houses.

One sensitive scale for weighing kiln samples. For very careful work a metric scale accurate to 1 gram, and with a capacity of about 20 kilograms, is most satisfactory. For rougher work an avoirdupois scale accurate to $\frac{1}{100}$ pound, and with a capacity of 50 pounds, will give good results. Scales weighing in either grams or decimal fractions of a pound are more desirable than those weighing in ounces and pounds.

One electric flashlight—lantern type, which can be hung on the arm, is preferred.

One can of hardened gloss oil or other protective coating and a brush.

Twelve packages of punk sticks or a "smoke machine," as illustrated in Fig. 86.

Waxed or oiled paper or oilcloth.

A crosscut saw and other ordinary tools.

116. Precautions to Be Observed in Piling the Lumber.—In loading a kiln certain precautions must be taken in piling the lumber so as to obtain the best results. This fact has already been discussed in Chap. VIII. In loading a kiln the following applies particularly to its operation:

1. Sufficient space should be left between the piles and the walls to give the operator access to all parts of the kiln.

2. As will be explained later, provision must be made so that the samples can be easily removed from the kiln.

3. If it is desired to know exactly what deteriorating effect the drying process will have on the stock, the extent of all defects present before drying, such as checks, shakes, honeycomb, cup, warp, and discoloration, should be marked with a lumbermen's crayon on each piece as it is placed in the kiln.

117. Selection and Placing of Samples.—In order to know definitely how the drying is progressing, it is necessary to take pieces out of the kiln from time to time and weigh them, or to cut smaller sections from them to see how rapidly they are losing in moisture content. If the kiln charge consists of lumber, it is impracticable, as a rule, to take out whole boards. However, short samples from 2 to 3 feet long, placed in various parts of the kiln, may be removed easily from time to time. The selecting and handling of these samples should be done as follows:

1. From approximately each 5,000 board feet of lumber that are placed in the kiln select three or more boards which, in size, moisture content, proportion of sapwood to heartwood, and

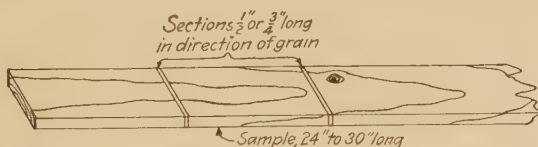


FIG. 108.—Showing method of cutting sample and sections from board.

method of sawing with relation to direction of grain, are as nearly representative of the average condition of the load as can be determined by handling. If there is considerable variation in the stock, select some boards which are of high moisture content and quarter-sawed.

2. Two or more feet from the end of each of the boards selected cut out a piece 24 to 30 inches in length (see Fig. 108); the piece to be chosen so as not to include knots, rot, serious cross-grain, or other defects. These pieces are called "samples." Number each sample.

3. Immediately, cut pieces about $\frac{1}{2}$ to $\frac{3}{4}$ inch long with the grain from each end of these samples and give them the same number as was given the sample from which they were cut. These pieces will subsequently be referred to as "sections" (see Fig. 108).

4. Rub or cut off the loose slivers, and without allowing the sections to dry weigh the two from each sample to an accuracy of one-tenth of 1 per cent on the small balance. Mark the weights on the sections. The sections cut from each sample need not be weighed separately. If these sections must be carried some distance or if for any reason some time must elapse before they are weighed, they should be wrapped in oil paper, oilcloth, or a damp rag from which as much moisture as possible has been wrung out, or placed in a closed container.

5. Place the sections in a drying oven heated to about 212°F.; or, if an oven is not available, place them on live steam pipes which will subject them to about the same temperature. Care must be taken not to scorch them. For further details in determining the moisture content of the sections, refer to page 27.

6. As soon as possible after cutting the sections from the samples, thoroughly coat the ends of the samples with a heavy coat of hardened gloss oil or some other coating as directed on page 57, in order to prevent loss of moisture from end drying.

7. After the ends are coated, weigh the samples separately on the larger scale to an accuracy of 1 gram or $\frac{1}{100}$ pound. Mark the weight on each sample, and also record it on the data sheet under the first day in the kiln (see sample sheet, Form A, Dry-kiln Record, page 266).

8. Place the samples in places previously arranged in the lumber pile so that out of every three one is placed where the drying is the most severe, one where the drying is the least severe, and one where the drying is medium or average, but do not place any samples in the lowest or the uppermost layers. As a rule, the most severe drying takes place where the hot air first enters the lumber pile, and the least severe where the air leaves or where the temperature is low and the humidity is high. The proper place for these samples can be determined from hygrometer readings in different parts of the kiln during previous runs. The samples should have both sides and both edges exposed to the air like the adjacent lumber, but the ends may butt up against other pieces unless whole pieces are used, as may be done for spokes and other small material, in which case the ends of the samples should be given the same treatment and exposure as the rest of the stock.

9. After the sections in the oven have become thoroughly dry, which will take from 6 to 48 hours, the length of time

depending upon the species, thickness, and original moisture content, weigh the two sections from each sample and compute their average original moisture content, as previously described. It is safe to assume that the percentage of original moisture was practically the same in the 2-foot samples as in the average of the section taken from each end. Record this original moisture per cent for each sample on the data sheet under the first day in the kiln (see Form A, page 266).

10. Knowing the original weight and the moisture content of the samples, their oven-dry weight can be calculated. For example: Original weight = 12.2 pounds; original moisture as determined from sections = 40 per cent based on oven-dry weight; then 140 per cent = 12.2, and 100 per cent (oven-dry weight) = 8.71 pounds. Record the calculated oven-dry weight of each sample on the data sheet (see Form A, page 266). On the basis of its calculated oven-dry weight, the moisture content of each sample in different stages of drying can be determined by the usual form of calculation without cutting test sections.

If short stock, like spokes, is to be dried, sections may be cut 3 or 4 inches from each end and the remaining middle portion used for a sample after it has been end coated. For very short stock, entire pieces must be used for samples, and in that case the ends must not be coated unless all the stock is end coated. The approximate original moisture content is then determined from sections cut out of other pieces.

118. Preliminary Steaming.—It usually is advantageous to steam lumber before the drying process begins. The steaming may be done in a separate chamber, but more often it is done in the kiln proper. In some progressive kilns the green end is partitioned off so that the green lumber can be steamed without greatly affecting the humidity in the rest of the kiln.

The chief purpose of steaming green wood, as already mentioned in Chap. VII, is to heat the lumber through before surface drying begins so as to hasten the transfusion of moisture from the interior to the surface. Steaming, whether at the beginning or later in the operation, also tends to equalize the moisture content by increasing it in the surface layer and decreasing it in the center of each piece (see Table XII, sixteenth day). As far as present scientific data go, there is no reason to believe that short steaming periods at atmospheric pressure change the organic constituents of the sap, as starches, sugars, tannin, etc., or change

TABLE XII.^a—DRYING RATE AND CONDITION OF 2½-INCH SITKA SPRUCE PLANK KILN DRIED IN SEVENTEEN DAYS,
USING INTERMITTENT AND FINAL STEAMING

Days in kiln	Tempera- ture, degrees Fahrenheit	Humidity, per cent	Percentage of moisture in 1-inch section cut from samples placed where drying conditions were average	Percentage of moisture in outer ¾-inch shell	Percentage of moisture in inner core ¾-inch thick	Difference between per- centage of moisture of outer ¾-inch shell and ¾-inch core	Steaming periods	Condition of stock
0	...	..	37.8	27.6	40.4	12.8	No preliminary steaming	Slightly air dried. Small amount of case- hardening present.
1	129	80	36.7	27.6	40.3	12.7	.....	Slight casehardening.
2	130	74	32.6	18.8	41.6	22.8	.....	Slight casehardening.
3	131	76	27.7	17.0	38.7	21.7	.....	Severe casehardening.
4	131	74	25.9	16.5	38.9	22.4	.....	Severe casehardening.
5	131	74	23.1	15.7	37.0	21.3	.....	Severe casehardening.
6	131	74	20.4 ^b	15.3 ^b	28.5 ^b	13.2	Steamed 1 hour at 160°F., 100 per cent humidity	Severe casehardening. Steaming removed casehardening only slightly. ^c
7	130	57	19.3	13.0	26.9	13.9	.....	Severe casehardening.
8	130	57	.....	.....	.....	.....	Steamed 1 hour at 155°F., 100 per cent humidity	Steaming had little effect on stock. ^c
9	141	48	17.3	12.2	23.6	11.4	.....	Severe casehardening.
10	146	39	15.1 ^b	11.1 ^b	19.6 ^b	8.5	Steamed 3 hours at 166°F., 100 per cent humidity	Steaming had little effect on stock. ^c
11	150	30	12.2	8.0	16.3	8.3	.....	Severe casehardening
12	150	30	.....	.....	.....	.....	.....	Severe casehardening
13	150	30	9.9	7.3	12.4	5.1	.....	Severe casehardening.
14	149	30	10.3	7.4	13.9	6.5	.....	Severe casehardening.
15	149	28	9.3	6.6	12.2	5.6	.....	Severe casehardening.

16	150	27	9.0	6.9	12.4	5.5	Before steaming. Steam- ed 4 hours at 165°F., 100 per cent humidity After steaming	Severe casehardening.
			10.4	10.5	11.9	1.4		Casehardening prac- tically relieved.
17	150	30	9.0	7.4	11.3	3.9	Steamed 4½ hours at 164°F., 100 per cent humidity. Moisture de- termination made after excess moisture added by steam to surface layers had been removed.	No casehardening.

^a This table is given here principally because it shows the moisture distribution throughout the drying period and the effect of steaming. It should not be construed as representing ideal conditions although the stock came through in excellent condition.

Data by L. K. POMEROY, Forest Products Laboratory.

^b Moisture determinations made before steaming.

^c On account of the thickness of the stock these steaming periods were not sufficient to remove the stresses in the lumber.

the wood itself sufficiently to be of importance in its further drying or later use.

Steaming plain-sawed green oak at a high temperature has a tendency to produce fine checks if the temperature and the humidity are lowered too rapidly afterward, because of the drying effect of the heat contained in the lumber. For this reason it is safer not to steam plain-sawed oak at a temperature much above the initial drying temperature, and to lower the humidity very gradually.

The length of time, the temperature, and the humidity required for both green and air-dried lumber which is to be steamed at the beginning of the run are given in Chap. VII.

119. Testing the Circulation.—In order to know whether the circulation is ample, whether the thermometers and the hygrometers are properly placed, and whether the samples are properly located, the nature of the circulation in the kiln should be determined. This can be done, as directed in Chap. VIII, after the temperature and humidity are properly adjusted for operating purposes.

The circulation may vary with different kiln temperatures, with different methods of piling, and with the seasons of the year; therefore, it should be tested repeatedly under varying kiln conditions.

120. Location and Calibration of Instruments.—The bulb of the recording thermometer should be placed where the hottest air enters the lumber pile, since that is the place where the lumber will first deteriorate from excessive heat. If the heating coils are underneath the lumber and the air rises vertically, the bulb of the thermometer should be near the bottom of the pile; if the hot air enters one side of the pile, the bulb should be placed on that side. The bulb must be shielded from direct radiation from the steam pipes or it will show a higher temperature than that of the air. There is little use in determining the temperature of the kiln near the door or in one corner.

To calibrate (that is, to test for accuracy) the recording thermometer, put the bulb in the proper location and place alongside of it an accurate glass thermometer, being sure that both are shielded from direct radiation. After at least one hour, during which time the temperature has not been fluctuating, read the temperature of the glass thermometer and compare the reading with the temperature indicated by the recorder on the chart.

If the two differ, adjust the stylus of the recording instrument so as to show the right temperature, or mark on the chart the number of degrees, plus or minus, by which the chart differs from the correct reading. This adjustment should be checked by another observation. To insure accuracy, the recorder should be calibrated following a period of rising temperature and also following a period of falling temperature and the correction based on the average of the readings in the two cases. The recording thermometer should be calibrated under actual working conditions at least once during each run. Never try to calibrate a recording thermometer under anything but working conditions, except to determine sensitiveness or lag, or to discover the variations, if any, in the error throughout the working range. If the kiln is not equipped with a recording thermometer, the readings of the dry-bulb thermometer of the hygrometer will serve to indicate the actual temperature.

Other glass thermometers may be placed in various parts of the kiln, especially where unusually low temperatures are expected. These thermometers should be checked occasionally with each other or with a standardized glass thermometer by placing them close together and wrapping a woolen cloth around the bulbs so as to keep out air currents.

The wet-and-dry bulb hygrometer should be checked by taking the wick off the wet bulb and observing whether the two thermometers read the same at dry-kiln temperatures, being careful to exclude any air currents. If they do not show the same temperature under these conditions, the instrument should be discarded or a correction made at every reading.

The hygrometer should be supplied with a clean wick and distilled water or clean rain water and placed in the kiln where the hot air first enters the lumber pile, being careful to shield it against direct radiation from the steam pipes. This is where the air is driest and where it may do the most damage to the lumber. In progressive kilns a hygrometer should be placed in each end of the kiln.

121. Observations during the Run.—From the very beginning of each kiln run the temperatures and humidities should be carefully determined, as previously directed. These should be recorded on proper forms, unless recording instruments are used, in which case the charts may be attached to the kiln record. In the absence of recording instruments, readings should be

taken every three hours, if possible, until the operator is thoroughly familiar with his kiln. He may be surprised to find great fluctuations in twenty-four hours. After the operation of the kiln has been standardized, readings taken two or three times a day are usually sufficient. Recording thermometers are very useful for obtaining records during the night. Although they are not always accurate, they can be checked up from time to time and corrections made. Maximum thermometers are valuable, since they show the highest temperature reached, which is the most important thing to know about the temperature.

The nature of the circulation should also be determined several times during the run to see if it changes any as the temperature increases.

The samples in the kiln should be weighed daily unless the drying period is longer than twelve days, in which case weighings may be made every other, or every third, day. The removing, weighing, and replacing of samples should be done as quickly as possible, since they may dry out somewhat when hot and moist if exposed to ordinary atmospheric humidities. The weights of the samples as determined from time to time should be recorded.

Since the oven-dry weight is known from previous calculations, the remaining percentage of moisture in the samples can readily be calculated. These data should be recorded on suitable forms (see Form A, page 266). A method employed at some plants for determining the dryness of the lumber in the kiln is to cut a thin section from a board, dry it on a steam pipe, and see how much it shrinks. This method is not so reliable as determining the dryness by the weight since the shrinkage varies with the species, with the density of the wood, with the direction in which the lumber is cut, that is, whether plain-sawed or quarter-sawed, and with the degree of casehardening.

After an operator has become thoroughly familiar with the kilns with which he works, he may find it satisfactory to use a smaller number of samples than a beginner should use.

It is very instructive to determine occasionally during the run the moisture distribution within a board or plank. This is done as described on page 27. The outer shell will always contain several per cent less moisture than the core as long as any drying is taking place; but if the difference is great, there is danger of checking and casehardening in the surface layers.

Table XII shows the moisture distribution in sections cut at frequent intervals from a kiln charge of Sitka spruce.

Casehardening tests during the run are also helpful in determining how the lumber is drying (see again pages 60 to 63 and Fig. 21). Figure 109 shows the condition of the Sitka spruce sections referred to in Table XII. If the outer portions

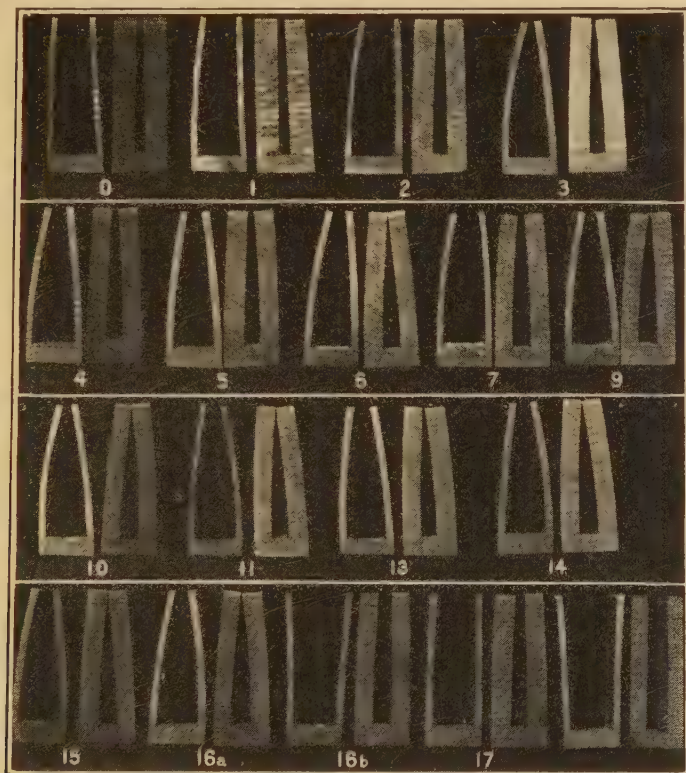


FIG. 109.—Test sections cut from spruce planks referred to in Table XII.
(Courtesy, Forest Products Laboratory.)

Figures indicate number of days in kiln—16a, before steaming; 16b, after steaming. The last set of sections was cut after the stock had been conditioned out-doors for two weeks.

of resawed sections cup outwardly as soon as sawed, the surface layers are much drier than the interior and are trying to shrink more. This usually happens in the early stage of drying but is no cause for alarm if the lumber does not check.¹ Plain oak and

¹ The resawed sections may also curve outwardly as a result of steaming at too high humidity to remove casehardening at the end of the run (see chap. IV, p. 65).

other woods which surface check easily may deteriorate a great deal if these stresses are too great.

If in a test during the drying period the halves of resawed sections cup inwardly immediately when they are resawed, an important stage in the operation has been reached. This means that the interior is trying to shrink, but the surface layers are set and internal tensile stresses are forming.¹ If the lumber is of a kind that honeycombs easily or retains these stresses permanently, the charge should be steamed to relieve the stresses, as directed in Chap. VII, Art. 86. After the steaming is completed, the doors and vents should be kept closed and the kiln allowed to cool slowly in a high humidity until the drying temperature is reached, when the coils can be turned on and drying resumed.

In cooling a kiln slowly after the lumber is steamed, it is well to guard against any stagnation of air which is liable to occur in the upper part of the kiln on account of the high temperature of the lumber and the tendency of the steam to rise to the top. It may be necessary at times to open the kiln doors for a few minutes, if there is no ventilator in the ceiling, to allow the hot steam to escape, or, in the water-spray kiln, to run cold water through the sprays until the normal circulation has been reestablished. In kilns equipped with ceiling coils, cold water may be run through the coils if the proper connections can be made. If some such provision is not made, there may be a region of very high temperature and saturation in the upper part of the kiln for many hours after the steaming is completed.

Surface checking occurs principally in the first half of the run, indicating that the surface is drying and shrinking much more rapidly than the interior. If the checking becomes serious, the humidity should be raised at once. If steam is used to raise the humidity, it is not necessary in this case to saturate the air. Only enough steam need be admitted to prevent further checking. Although excessive steaming may close up the checks, the condition will only be temporary, and they will open up again even more and new ones may form, after drying is resumed. Steaming is not effective in preventing checking after the steaming is discontinued; it is simply a means of preventing any further checking for the time being.

¹ Lumber which is steamed or held at a high humidity for a considerable time near the end of the run, that is, after the interior is fairly dry, may also cup inwardly on resawing; but cupping due to this cause alone is temporary and disappears when the surface is redried.

If for any reason it becomes necessary to allow the kiln to cool down, it is best to keep it closed as tight as possible so that the temperature and humidity will lower gradually, since the heat contained in the lumber will lower the humidity of fresh air to such an extent as to cause surface checking, and possibly casehardening (see Chap. VII, footnote, p. 156).

Honeycombing must be watched for during the latter part of the run. It should be remembered that, as a rule, it cannot be seen at the end of a piece, the only sure way to detect it being to cut through a number of pieces. If the tangential surfaces have a caved-in appearance, however, it is a good indication of honeycombing within. To prevent further damage of this nature the lumber should be steamed and then the humidity kept somewhat higher for a while. Steaming will relieve the stresses in this condition, and thereby prevent additional internal checking.

Mold very often forms on green lumber which must be dried at comparatively low temperatures and high humidities. Mold is the cause of a great deal of trouble in drying heavy green oak stock and may become so thick as to close up the spaces between adjacent pieces, or even hang down as "whiskers." The principal objection to mold is that it interferes with the circulation. The visible growth of mold may be killed by steaming the stock, as explained in Chap. VII, page 180. Another method of killing mold is to lower the humidity to about 60 per cent for about four hours, or just long enough to dry the mold but not surface dry the lumber too much. In either case the spores are not killed, and a new growth may develop, making it necessary later on to repeat the process. In extreme cases, mold may be developed to such an extent that, even after killing it, it may be necessary to remove it mechanically so as to open the air passages again.

122. Tests at the End of the Run.—When the samples show by their weight that they have been dried to the desired moisture content, a number of tests should be made to see if the lumber is properly dried. Such superficial indications of the condition of the lumber as its "smell" or "ring," or the way it whittles serve only if the material is to be used for the most unexactng purposes. For almost all classes of work the lumber should be given more rigorous and significant tests. These may be made as follows:

The samples are taken out of the kiln and from the middle of each one three 1-inch sections, *a*, *b*, and *c* (Fig. 110), are cut and the following tests made on them:

(a) *For Moisture Content*.—Section *a* is weighed immediately and placed in the drying oven. When it has reached a constant weight, its *actual* moisture content is determined to see if it agrees with the calculated moisture content previously assumed to be correct. If the actual moisture content is too high, the drying should be continued until the proper degree of dryness is attained.

(b) *For Moisture Distribution*.—Section *b* is sawed or split so as to have an outer layer and a core, as explained on pages 27 and 28 and illustrated in Fig. 6. The moisture content of the outer and inner portions is determined separately to see what

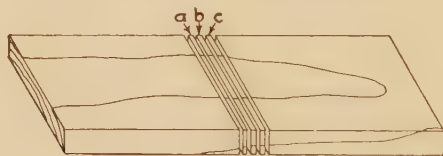


FIG. 110.—Showing method of cutting sample at end of drying period.

the difference is. The moisture content of the core should not exceed that of the surface layers by more than 2 per cent for each inch in thickness of lumber used for high-grade work.

(c) *For Casehardening*.—Section *c* is tested for casehardening, as previously described, by letting the section dry overnight or twenty-four hours in a warm room, but not in the oven or on steam pipes, *before* it is resawed. The degree of cupping toward the inside, when the dried section is resawed, indicates the severity of the stresses that will be present in the lumber after its moisture content has become fairly uniform.

Similar tests, especially for moisture content, should also be made on some of the whole pieces in the kiln because the samples often dry more rapidly than the larger pieces.

If the moisture content is not low enough, the drying must be continued.

If the average moisture content is satisfactory but the inner core of the lumber is very moist while the outer shell is too dry, the stock should be held at a humidity corresponding to the desired moisture content of the lumber (see Fig. 11) and a tem-

perature of 165 to 185°F., so that the moisture is given an opportunity to become more evenly distributed within the pieces.

If severe casehardening seems to be present, the stock must be steamed so as to relieve the stresses (see Chap. VII, Art. 86 for details regarding steaming).

Another method which is usually sufficient to overcome casehardening and also hastens the drying of the interior is to dry the outer shell purposely to 3 or 4 per cent below, and the inner core to about, the final moisture content, and then raise the humidity so as to increase the moisture content of the outer shell to the desired percentage, keeping the temperature in the meanwhile at about 180°F. This method, of course, is not applicable to woods which are to be dried down to 4 or 5 per cent, but it can be used on rough lumber, or vehicle stock which is dried to only 10 or 12 per cent.

123. Keeping Records.—Modern business efficiency demands that records be kept of all data which may be of use as a guide in future practice or as evidence of past actions. This applies to kiln drying lumber as well as to accounting or any other branch of business. If a kiln run has been particularly successful, a record of the temperatures and humidities used and the kind of lumber dried will be of great value for the next similar run. On the other hand, if the lumber has been badly checked, casehardened, or honeycombed, it will be highly desirable not to repeat that operation. If a kiln operator is charged with using improper methods in drying lumber, his records will show to a large extent the truth or the fallacy of the charges preferred.

The form on page 266 is a sample blank for keeping kiln records. It is prepared merely as a guide and may be modified to meet individual needs. It may be desirable to record additional data or not so much as indicated, depending upon the operator and the nature of the operation. If a larger number of readings are taken, or if a larger number of samples are used in the kiln, it may be necessary to use two forms, one for recording the temperatures and the humidities, and the other for the weights and the moisture contents of the samples. Special columns may also be provided to indicate the following: the moisture content of boards other than the samples; shrinkage measurements; position of dampers, heating-coil valves, steam-jet valves, and condensing-coil valves; steam pressures; water pressures; speed of fan; outdoor temperature; direction of wind (particularly

for progressive kilns with longitudinal circulation); and other items, depending upon how intensive a record of conditions is desired. It may be found desirable to have two types of forms: one, a simple form for regular runs; and one, much more elaborate, for the test or experimental runs.

Figure 111 illustrates how the temperature, humidity, and moisture content for a kiln run may be represented graphically.

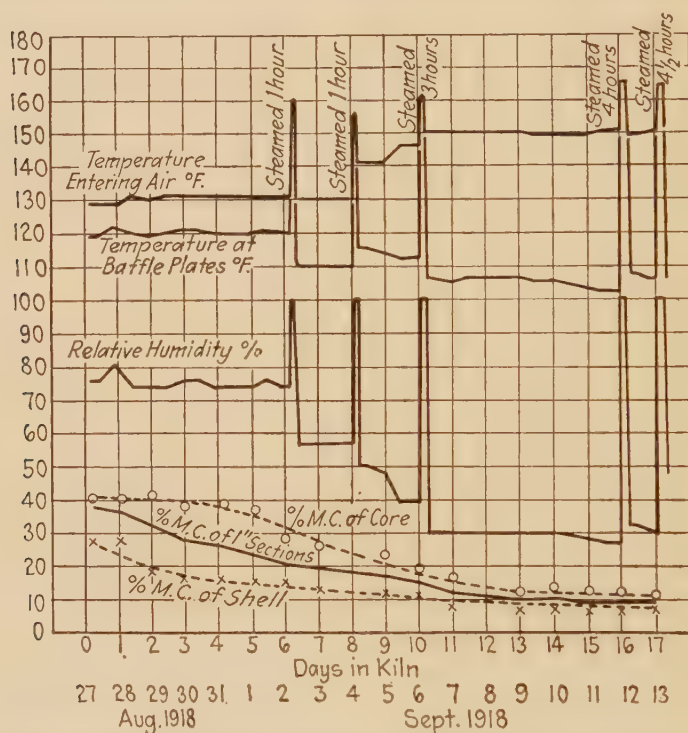


FIG. 111.—Graphic presentation of temperature, humidity, and drying rate of the Sitka spruce referred to in Table XII. (Courtesy, Forest Products Laboratory.)

This lumber was dried in a water-spray kiln. At the baffle plates the air has passed through the water sprays and is about to be reheated. Note: Steaming at 100 per cent humidity to relieve stresses is no longer recommended.

This form gives a better idea of the conditions existing in the kiln during that run than Table XII does.

124. Drying Schedules.—In order to dry lumber quickly and at the same time have it come out of the kiln as good in quality as is consistent with the purpose for which it is to be used, it is necessary to follow a schedule of temperatures and humidities

which has been tried out and has given satisfactory results with previous kiln charges of similar material. With the increasing price of lumber, guesswork must be replaced by systematized action. Old methods, like leaving the lumber in the kiln for a certain number of days at whatever temperature can be maintained in the kiln, and with little or no regard for humidity, must be replaced by painstaking and thoughtful procedure based on certain fundamental principles which govern the drying of wood if efficiency is any object in the operation of a kiln.

The drying schedules given here were prepared by the Forest Products Laboratory as a result of many years of experimentation. They are intended to be used as a guide for drying various kinds of wood which are to meet with exacting requirements, such as furniture, vehicles, pattern stock, etc.

For less exacting purposes, in which a certain reduction in quality is permitted, somewhat higher temperatures and lower humidities may be used with a corresponding shortening of the drying period. If an operator is called on to dry lumber of a species or thickness not covered by the schedules, it will be advisable for him to dry the first charge under a safe schedule, that is, one with a comparatively low temperature and high humidity, such as Schedule 7 or 8. If the temperatures and humidities tried give good results, a severer schedule may be tried in a subsequent charge, and so on until the condition of the lumber indicates that the danger point is reached and that it is not safe to use more severe conditions if the quality of the stock is to be maintained.

Following the schedules are lists of softwood and hardwood species with indexes of the schedules to be used in drying them. The schedules indicated for the hardwood species are safe for drying lumber up to $\frac{3}{4}$ inch thick. For each inch over $\frac{3}{4}$ in thickness a schedule one milder (numbered one higher) than the one listed for the species should be used. The schedules to be followed in drying different thicknesses of softwood lumber are given in the index of schedules for softwoods. When it is necessary to dry at one time in the kiln two or more kinds of lumber requiring different drying schedules, the mildest of the schedules required should be followed.

It will be noticed that any condition of temperature and humidity is based in each schedule on the *moisture content* of the lumber. This should be the guiding principle in all cases,

and not the number of days the lumber has been in the kiln. The purpose of kiln drying lumber is to remove a large part of the moisture and leave a certain percentage. When this object is obtained in a way that does not impair the quality of the timber, the drying may be considered completed, and not before. For example, oak coming from one region may have more moisture in it than oak from another region, or one lot may have been on sticks longer than another lot and, consequently, different lengths of time will be required for drying. An exception in which the drying may be done in a specified number of days is lumber of uniform quality and moisture content, which is not to be used for exacting purposes, and which has been dried repeatedly under fixed conditions, so that it is known just how long it takes to dry a kiln charge, for example, 1-inch yellow pine, Douglas fir, hemlock, etc. for general construction.

In the softwood schedules the temperatures and humidities given in the first line should be maintained until the moisture content is down to that indicated in the second line in each division. When this stage is reached, the temperature may be raised and the humidity lowered to correspond with the figures in the second line. In the hardwood schedules, the first change is made at a moisture content of 40 per cent.

SCHEDULE 000

The most severe softwood drying schedule

Moisture content of the stock at which the changes should be made				Dry-bulb temperature in degrees Fahrenheit	Wet-bulb temperature in degrees Fahrenheit	Relative humidity, per cent
Div. I	Div. II	Div. III	Div. IV			
Initial	Initial	Initial	Initial	180	165	70
40	35	30	25	190	161	50
20	16	13	13	200	150	30

Temperatures for vertical-grain flooring strips may be 10° higher than those in the schedule after the stock has dried down to a moisture content of 25 per cent.

A medium softwood drying schedule

Moisture content of the stock at which the changes should be made				Dry-bulb temperature in degrees Fahrenheit	Wet-bulb temperature in degrees Fahrenheit	Relative humidity, per cent
Div. I	Div. II	Div. III	Div. IV			
Initial	Initial	Initial	Initial	160	146	70
40	35	30	25	170	144	50
20	16	13	13	180	135	30

The mildest softwood drying schedule

Moisture content of the stock at which the changes should be made			Dry-bulb temperature in degrees Fahrenheit	Wet-bulb temperature in degrees Fahrenheit	Relative humidity, per cent
Div. I	Div. II	Div. III			
Initial	Initial	Initial	135	123	70
30	25	20	150	126	50
20	16	13	165	132	40
15	12	10	175	130	30

[illegible]

HARDWOOD SCHEDULES 5 TO 8

Stock moisture content	Schedule 5			Schedule 6			Schedule 7			Schedule 8		
	Dry-bulb temperature	Wet-bulb temperature	Relative humidity, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity, per cent
Above												
40	120	113	80	115	108	80	110	105	85	105	101	85
40	125	116	75	120	111	75	115	108	80	110	104	80
30	130	119	70	125	114	70	120	110	75	115	107	75
25	135	121	65	130	116	65	126	112	65	120	109	70
20	140	120	55	135	116	55	130	112	55	125	110	60
15	145	119	45	140	115	45	135	111	45	130	109	50
10	150	112	30	145	108	30	140	108	35	135	107	40
to final												

INDEX OF SCHEDULES FOR DRYING SOFTWARED LUMBER

Species	Size	Schedule	Remarks
Cedar, Port Orford.....	$\frac{3}{4}$ - $\frac{9}{4}$	00-III	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-IV	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-IV	Wide, clear, no sinkers
Cedar, western red.....	$\frac{3}{4}$ - $\frac{9}{4}$	0-III	Sinker
	$\frac{7}{4}$ - $\frac{9}{4}$	00-III	Free from sinkers
	$\frac{7}{4}$ - $\frac{9}{4}$	0-III	Sinker
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-III	
Cedar, white (northern and southern)...	$\frac{3}{4}$ - $\frac{9}{4}$	00-II	Flat grain
	$\frac{7}{4}$ - $\frac{9}{4}$	00-III	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-II	
Cypress, bald.....	$\frac{3}{4}$ - $\frac{9}{4}$	00-I	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-II	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
Douglas fir.....	$3\frac{1}{2}$ - $4\frac{1}{2}$	00-IV	Cross-arms
	$\frac{3}{4}$ - $\frac{9}{4}$	000-IV	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-IV	Wide, flat grain
	$\frac{7}{4}$ - $\frac{9}{4}$	00-IV	
Fir, balsam.....	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-III	
	$\frac{3}{4}$ - $\frac{9}{4}$	000-I	Wide, flat grain
	$\frac{7}{4}$ - $\frac{9}{4}$	000-II	Wide, flat grain
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
Fir, lowland white.....	$\frac{3}{4}$ - $\frac{9}{4}$	000-I	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-I	Wide, flat grain
	$\frac{7}{4}$ - $\frac{9}{4}$	000-II	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-II	Wide, flat grain
Fir, noble.....	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
	$\frac{3}{4}$ - $\frac{9}{4}$	000-III	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-III	Wide, flat grain
	$\frac{7}{4}$ - $\frac{9}{4}$	000-IV	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-IV	Wide, flat grain
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-III	

INDEX OF SCHEDULES FOR DRYING SOFTWOOD LUMBER.—*Continued*

Species	Size	Schedule	Remarks
Fir, white.....	$\frac{3}{4}$ - $\frac{9}{4}$	000-I	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-I	Wide, flat grain
	$\frac{7}{4}$ - $\frac{9}{4}$	000-II	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-II	Wide, flat grain
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
Hemlock, eastern.....	$\frac{3}{4}$ - $\frac{9}{4}$	00-I	Uppers
	$\frac{7}{4}$ - $\frac{9}{4}$	00-II	Uppers
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
Hemlock, western.....	$\frac{3}{4}$ - $\frac{9}{4}$	000-I	
	$\frac{7}{4}$ - $\frac{9}{4}$	000-II	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
Larch, western.....	$\frac{3}{4}$ - $\frac{9}{4}$	00-II	Uppers
	$\frac{7}{4}$ - $\frac{9}{4}$	00-III	Uppers
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-II	
Pine, Norway.....	$\frac{3}{4}$ - $\frac{9}{4}$	000-II	
	$\frac{7}{4}$ - $\frac{9}{4}$	000-III	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-II	
Pines, southern yellow.....	$\frac{3}{4}$ - $\frac{9}{4}$	000-I	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-I	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
Pine, western yellow.....	$\frac{3}{4}$ - $\frac{9}{4}$	000-I	Avoid preliminary steaming.
	$\frac{7}{4}$ - $\frac{9}{4}$	00-I	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
Pine, white (eastern and western).....	$\frac{3}{4}$ - $\frac{9}{4}$	00-II	Uppers
	$\frac{7}{4}$ - $\frac{9}{4}$	00-III	Uppers
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-II	
Redwood.....	$\frac{3}{4}$ - $\frac{9}{4}$	00-I	Free from sinkers
	$\frac{7}{4}$ - $\frac{9}{4}$	0-I	Sinker
	$\frac{7}{4}$ - $\frac{9}{4}$	00-II	Free from sinkers
Spruce, Englemann.....	$\frac{7}{4}$ - $\frac{9}{4}$	0-II	Sinker
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-II	
Spruce, red.....	$\frac{7}{4}$ - $\frac{9}{4}$	00-III	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-III	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-III	
Spruce, Sitka.....	$\frac{7}{4}$ - $\frac{9}{4}$	00-IV	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-I	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-II	Wide, flat grain
Spruce, white.....	$\frac{3}{4}$ - $\frac{9}{4}$	00-II	
	$\frac{7}{4}$ - $\frac{9}{4}$	000-III	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-III	Wide, flat grain
Tamarack.....	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-II	
	$\frac{3}{4}$ - $\frac{9}{4}$	000-III	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-III	Wide, flat grain
	$\frac{7}{4}$ - $\frac{9}{4}$	00-IV	Wide, flat grain
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-III	
	$\frac{3}{4}$ - $\frac{9}{4}$	00-II	
	$\frac{7}{4}$ - $\frac{9}{4}$	00-III	
	$1\frac{1}{4}$ - $1\frac{3}{4}$	0-II	

INDEX OF SCHEDULES FOR DRYING HARDWOOD LUMBER

(Up to $\frac{3}{4}$ inch thick)

Species	Schedule	Remarks
Ash.....	2	
Basswood.....	1	
Beech.....	3	Relieve stresses often
Birch.....	1	
Boxwood.....	5	Squares or quartered stock only
Butternut.....	2	
Cherry, black.....	5	
Chestnut.....	2	Relieve stresses often
Cottonwood.....	2	
Elm.....	2	
Gum, black.....	3	
Gum, red.....	2	Including "sap gum"
Hackberry.....	2	
Hickory.....	5	
Holly, American.....	4	
Hornbeam (ironwood).....	4	
Locust.....	5	
Magnolia.....	4	
Mahogany.....	4	
Maple, hard and soft.....	3	
Oak, red and white.....	6	Northern highland stock
	8	Southern lowland stock
	7	Northern lowland, Southern highland
Osage orange.....	5	
Persimmon.....	5	
Poplar, yellow.....	1	
Sycamore.....	5	
Tupelo.....	3	
Walnut, black.....	5	
Willow.....	2	

The schedules given do not apply to any particular kind or type of kiln. They apply to the *kind of wood* for which they are intended. Any kiln in which the temperatures and humidities given for each stage of the operation can be maintained fairly uniform throughout the piles will give satisfactory results.¹

¹ In ordinary progressive kilns it is practically impossible to control the temperature and humidity in each stage of drying, and under such conditions it would be difficult to try to follow any schedule throughout the drying of

It may be necessary, however, to emphasize again that the temperatures must be measured where the air within the lumber pile is the hottest and the humidity is the lowest. These schedules will not give satisfactory results if their use is based on readings taken near a cold wall or door.

In using these schedules, satisfactory results cannot be expected unless the progress of drying is closely watched and frequent determinations made of the moisture content and moisture distribution with respect to the outer shell and the inner core. Also stresses which may cause damage to the lumber must be relieved by steaming or high humidity treatment at the proper time.

In many ventilated compartment kilns, it is not possible to maintain satisfactorily the high humidities recommended for green stock, and it becomes necessary to start the drying at lower humidities.

Common grades of Douglas fir and the southern yellow pines can be dried with schedules in which both temperature and humidity are maintained constant throughout the run. For 1×6 , 1×8 , 2×4 , and 2×6 Douglas fir a temperature of 175°F. and a humidity of 70 per cent are recommended. For 1×10 , 1×12 , 2×8 , 2×10 , and 2×12 stock a humidity of 80 per cent should be used for the first half of the run, dropping then to 70 per cent.

For one-inch southern yellow pine a temperature of 180°F. and a humidity of 60 per cent are recommended. Final moistures of about 15 per cent are secured with these schedules.

each truck load, although reasonably satisfactory conditions can usually be approximated at the two ends of the kiln by the proper manipulation of the equipment.

CHAPTER XI

MISCELLANEOUS CONSIDERATIONS

125. Factors Which Affect the Time Required for Drying Lumber.—The time required to kiln dry lumber is an important consideration from a commercial standpoint. It affects not only the cost of kiln operation, but also the speed with which a job can be turned out, particularly special orders for which a certain kind of lumber must first be seasoned. Assuming that the kiln is suitable for drying lumber and that the lumber is properly piled, the following factors determine the time required for drying.

(a) *Circulation.*—As stated in Chap. VIII, the purpose of circulation is to keep the temperature and the humidity fairly uniform and proper within the lumber piles. With a sluggish movement of air, some parts of a kiln charge dry much more slowly than others. This holds up the whole operation. With a positive circulation all the lumber in the charge dries in approximately the same time, and the time of drying may be reduced to the minimum for any given conditions. If the lumber piles are comparatively wide, there is an appreciable difference in the drying rate of the part of the pile where the air first enters and the part where the air leaves. Hence, small compartment kilns or kilns with reversible circulation are more likely to dry lumber to a uniform moisture content quickly than large kilns.

(b) *Temperature and Humidity.*—In general, the higher the temperature and the lower the humidity the faster the lumber dries, provided the surface layers do not become so dry as to interfere to too great an extent with the transfusion of moisture from the interior. If excessive surface drying does take place, intermittent steaming may materially hasten the drying of some woods, whereas the advantages of steaming other woods are less pronounced. Maintaining a high relative humidity while the center of the stock still has a high moisture content has been found to dry the center faster than using a low humidity from the beginning.

(c) *The Purpose for Which the Lumber Is to Be Used.*—In drying lumber in which the maximum amount of strength is essential, for example, airplanes and some athletic goods, lower temperatures must be maintained than could safely be used for drying the same lumber for many other purposes, as interior finish, patterns, and most furniture. Consequently, a longer drying period is required for such stock.

(d) *Species.*—Some woods, for some undetermined reason, dry more easily than others with the same initial moisture content and under the same conditions; that is, there is a difference in the rate at which moisture transpires from the interior. Cypress and redwood, for example, dry more slowly than most other coniferous woods.

(e) *Density or Dry Weight.*—There is considerable variation in the density of the wood of the same species, or even of the same tree. With the same weight of moisture per cubic inch, the drying rate of dense material is much slower, as a rule, than that of light material because the moisture seems to diffuse more easily through the lighter wood. With the same *percentage* of moisture, based on the dry weight of the wood, the denser piece contains more moisture per unit volume, and for this reason alone it takes longer for it to dry than a light piece having the same percentage of moisture by weight. Furthermore, because dense wood shrinks more than light wood, checking and casehardening are more apt to occur in heavier pieces. For this reason they must be dried more slowly and carefully.

(f) *Moisture Content.*—Obviously, the time required for drying increases with the amount of moisture that must be evaporated. The moisture content varies in the same species, and even in the different parts of the same tree; it varies greatly in different species, and also with the amount of preliminary air seasoning.

(g) *Sapwood or Heartwood.*—Sapwood dries more quickly than heartwood, the moisture content being the same or even less. For example, in a certain kiln run of $1\frac{1}{2}$ -inch western yellow pine lumber, the sapwood, with a moisture content of 133 per cent, and the heartwood with a moisture content of 32 per cent, were both reduced to 8 per cent moisture in the same length of time.

(h) *Portion of Tree from Which Lumber Is Cut.*—In many species, lumber from the butt logs requires more time for drying than that from the top logs. This is accounted for principally

by the greater density and higher moisture content of the butt logs. The so-called "sinker stock" from butts of western red cedar and redwood is an extreme example.

(i) *Thickness of Lumber*.—Other conditions being the same, the time required for drying lumber which is from about $\frac{3}{4}$ inch to about 3 inches in thickness is approximately proportional to the thickness. For example, 2-inch lumber requires about twice as much time as 1-inch lumber of the same kind.

For lumber over 3 inches thick, the drying time increases more rapidly than the thickness. For example, 4-inch lumber requires considerably more than twice as much time for drying than 2-inch lumber of the same kind.

For stock less than $\frac{3}{4}$ inch in thickness, the drying time decreases more rapidly than the thickness. For example, $\frac{1}{4}$ -inch stock dries in less than one-half of the time required for $\frac{1}{2}$ -inch stock of the same kind.

(j) *Width of Pieces*.—Pieces which are square or nearly so in cross-section dry more rapidly than wider pieces of the same thickness. For example, a dimension piece 3 by 4 inches will dry more rapidly than a plank 3 by 8 inches because in a piece which is approximately square in cross-section the moisture from the center transfuses nearly equally to all surfaces, whereas in a wider piece of the same thickness the center moisture is evaporated principally from the two wide surfaces.

(k) *Quarter-sawed or Plain-sawed Lumber*.—Although plain-sawed lumber dries more rapidly than quarter-sawed lumber under the same conditions, more time is often required to dry plain-sawed lumber in the kiln than quarter-sawed lumber of the same kind and thickness, because the former must be given milder treatment, since it checks and casehardens more easily in drying.

(l) *Direction of Grain*.—Short end-grain stock, such as that used for wood-engraving blocks, for example, dries in a shorter time than ordinary lumber of the same thickness. Boards containing severe cross-grain probably dry in a shorter time than straight-grained lumber, although definite data on this subject are lacking. It might be well, however, to avoid the use of kiln samples in which the grain runs from one face to the other at a considerable angle, unless most of the stock is of the same nature, so as to eliminate, to some extent, the possibility of the samples drying more rapidly than the regular stock.

126. Effect of Kiln Drying on the Strength of Wood.—There is a common belief among lumbermen and woodworkers that kiln-dried wood is inferior in strength to air-dried wood. The expression commonly used is that kiln drying “takes the life out of lumber.” The following two factors are chiefly responsible for this belief, but they do not justify the assumption that all lumber dried in a kiln is necessarily weaker than similar air-dried material:

1. Occasionally wood is kiln dried under such unfavorable conditions of temperature and humidity that it is far inferior in strength to similar air-dried material.

2. Very dry wood is more brittle than wood of a higher moisture content. Therefore, a piece of wood kiln dried to, say, 4 or 5 per cent moisture will break off more abruptly and with fewer splinters and less bending than a similar air-dried piece having, say, 15 per cent moisture. This, however, does not mean that it takes less force to break the kiln-dried piece, or that it has been injured in drying. The difference in the way it breaks may be due entirely to differences in the dryness of the two pieces. The practice of splitting off a sliver from a piece of wood and breaking it is not a satisfactory test of the effect of kiln drying on the strength of the wood, since usually only the character of the failure, and not the force required to break the splinter, is taken into consideration. In fact, unless the wood is kiln dried under very unfavorable conditions, it takes more force to break a kiln-dried piece than an air-dried piece of the same size and quality but with more moisture in it, because the strength increases, as a rule, as the moisture decreases below the fiber-saturation point. Nevertheless, a piece of wood which has been dried to 3 or 4 per cent and is then allowed to reabsorb moisture to 15 per cent is somewhat weaker and more brittle than a similar piece of wood which has never been dried to below 15 per cent.

Table XIII shows the effect of changing the moisture content, within certain limits, on the mechanical properties of wood.

It will be noticed from the table that, as wood dries, all strength properties except toughness are increased, although not in the same ratio. The toughness of a dry piece of wood is less on the average because it will not bend so far before it breaks as a similar green piece, although it will hold up more weight. To be shock-resistant, or tough, a piece of wood must be pliable as well as strong in bending. In hardwoods, especially, there is a

TABLE XIII.^a—APPROXIMATE AVERAGE INCREASE IN STRENGTH EFFECTED BY LOWERING THE MOISTURE CONTENT OF WOOD 1 PER CENT, OR DECREASE EFFECTED BY RAISING THE MOISTURE CONTENT 1 PER CENT, WHEN AT ABOUT 12 PER CENT

STRENGTH PROPERTY	PER CENT
Cross-breaking strength, or modulus of rupture.....	4
Stiffness, or modulus of elasticity.....	2
Shock-resisting ability, or toughness.....	-2
Maximum strength in compression along grain.....	4
Fiber stress at elastic limit in compression across grain.....	6
Hardness, end grain.....	3
Hardness, side grain.....	1
Shearing strength along grain.....	4
Tension across grain.....	1

^a From NEWLIN, J. A., and WILSON, T. R. C., "Mechanical Properties of Woods Grown in the United States," United States Department of Agriculture *Bull.* 556.

decrease in toughness when drying takes place, whereas in conifers there is often a decided increase in toughness with a decrease of moisture content.

That wood carefully kiln dried under proper temperatures and humidities is, in general, fully as strong as air-dried material of the same quality and moisture content is shown by the results of over 100,000 tests made by the Forest Products Laboratory in connection with the kiln drying of wood for airplane construction. These tests cover twenty-six species and about one-hundred kiln charges. They also show, on the contrary, that wood may have its strength properties—particularly toughness, or resistance to shock—seriously damaged by improper drying methods without any visible evidence of such damage. But, as stated in Chap. I, there is no reason why lumber cannot be dried just as well by mechanical means and even better than by the natural elements, provided the drying conditions in the kiln can be properly controlled.

When wood has been injured in kiln drying so that it is not so strong as similar air-dried material, certain physical or chemical changes have taken place in it as follows:

(a) *Physical Changes*.—The physical changes are manifested either as checks or stresses due to uneven shrinkage. The checks may be readily visible or they may be only microscopic, as within the cell walls, but they have a certain weakening effect. The microscopic checks occur to some extent even in carefully dried wood and probably are partly responsible for the brittleness of wood which has been dried to a low moisture content. Severe

internal stresses may be set up within the wood, as in casehardening. Such internal stresses reduce the maximum external load that the wood can carry.

(b) *Chemical Changes*.—Whether the removal of moisture in itself causes any chemical changes in wood substance is not known, but it is a well-established fact that heat, if severe enough, will cause a decided chemical change in wood with a corresponding reduction in strength. The first indication of such changes is a decrease in toughness of the wood. With increased temperature the wood becomes brownish in color and becomes weakened in other respects, such as static bending and compression along the grain. If the heat is great enough, the wood finally becomes brash and turns to charcoal. In a kiln, an appreciable reduction in strength properties and brownish discoloration may result from using high temperatures, but rarely are the temperatures high enough to char the wood.

There is no well-defined temperature above which chemical changes, which have a weakening effect, take place in wood and below which no injury occurs. The weakening increases with the temperature and with the length of time during which the wood is exposed to that temperature. Some woods subjected to a temperature of 175°F. for one week in a kiln will suffer more from the heat than if steamed for several hours at 212°F. Furthermore, different species vary in this respect.

By proper methods of drying, both the physical and the chemical changes that affect the strength can be reduced to a minimum and the greatest possible strength of the wood preserved.

In air drying lumber the chemical changes probably are reduced to a minimum, unless decay sets in; but the physical changes, such as checking, casehardening, and honeycombing, may take place and little can be done to prevent them. In kiln drying lumber such injuries can be avoided, at least to a large extent.

Bad effects of kiln drying are usually due to too high a temperature or too low a humidity, or to a combination of the two. No definite rule can be laid down as to the maximum temperatures and the minimum humidities at which wood can be dried without seriously reducing its strength. In fact, these vary with the kind of wood and with the purpose for which it is to be used. For example, spruce can be dried at a higher temperature than fir without any injury, and a certain reduction in strength might not be serious for furniture, whereas for athletic goods it would be detrimental.

According to tests made at the Forest Products Laboratory, the temperatures and humidities given in Table XIV will not injure lumber in a kiln; in fact, the temperature may be raised 15° during short steaming periods.

TABLE XIV.—SCHEDULES SPECIFIED BY THE WAR AND NAVY DEPARTMENTS FOR DRYING AIRPLANE STOCK

Stage of drying	Drying conditions for ash, birch, maple, cedar, cypress, pine, and spruce		Drying conditions for cherry, mahogany, oak, walnut, and Douglas fir	
	Maximum tempera- ture, degrees Fahrenheit	Minimum humidity, per cent	Maximum tempera- ture, degrees Fahrenheit	Minimum humidity, per cent
At the beginning.....	120	80	105	84
At 25 per cent moisture.....	125	70	110	73
At 20 per cent moisture.....	128	60	117	62
At 15 per cent moisture.....	138	44	129	46
At 12 per cent moisture.....	142	38	135	43
At 8 per cent moisture.....	145	33	135	40
Final.....	145	33	135	40

These conditions, based on previous experience in kiln drying and on strength tests, were recommended by the Forest Products Laboratory and adopted by the War and Navy Departments for drying airplane material, and later they were verified by a large series of tests. For less exacting demands somewhat higher temperatures and somewhat lower humidities, than those given in the schedules in Chap. X, may safely be used without serious depreciation of the strength of the material.

127. Care of Lumber before Kiln Drying.—It is just as important to give lumber the proper care before it is put into the kiln as it is to operate the dry kiln properly. Considerable deterioration of the lumber may, and often does, take place while it is in storage preparatory to kiln drying. In fact, the losses due to preliminary air seasoning sometimes run over 50 per cent of the value of the stock. Such losses, together with the interest on the investment, often justify kiln drying the lumber in the green condition, where this is practicable. The following kinds of deterioration may take place in lumber before kiln drying:

(a) *Checking*.—Both surface checking and end checking may become very serious in air seasoning. Little can be done to prevent surface checking. Piling the lumber close together without stickers will prevent surface checks; but in summer, when checking chiefly occurs, it is not safe with many species to pile the lumber close together, since stain and decay may set in. The use of thin stickers is, however, often helpful.

End checking can be reduced by shading the ends of the pile, by painting the ends with a suitable end coating, or by nailing wooden or metal strips across the ends of the boards, as is sometimes done with mahogany and other high-grade woods.

(b) *Twisting and Cupping*.—These defects can be avoided largely by using sufficient stickers properly aligned, and leaving no unsupported ends.

(c) *Casehardening and Honeycombing*.—Some woods, especially thick oak, develop these defects very easily in warm, dry weather. Practically nothing can be done to prevent these in air seasoning, except slow, uniform drying.

(d) *Stain*.—Blue stain, or sap stain, is a common defect of the sapwood of many species when the moist wood is exposed in warm, and especially humid, weather. It is due to a fungus which lives on the nutritive materials in the sap of the sapwood. As soon as the sap dries up, the fungus becomes inactive. It does no serious harm except that it affects the appearance of the lumber. If the lumber is stacked in narrow, open piles, the amount of deterioration caused by blue stain is reduced, especially during the first two weeks of seasoning, but it is not entirely prevented. At some mills during moist, warm weather the lumber is dipped in a soda solution as it comes from the saw. This reduces the blue stain in subsequent air drying. The stickers should be of heartwood, since sapwood may harbor the fungus that causes blue stain and decay. Steaming preliminary to air seasoning, as practiced principally with red and "sap" gum lumber, reduces the tendency to blue stain in the sapwood.

California sugar pine is subject to a brown stain, the exact cause of which is not known, except that it is not due to a fungus. Favorable drying conditions reduce this stain to a minimum.

(e) *Decay*.—If green lumber is placed so that it cannot dry, or dries very slowly, the heartwood of many species and the sapwood of all species will decay in a comparatively short time in warm weather. If lumber is piled close together or kept from

seasoning in some other way, the heartwood of non-durable species and the sapwood of all species will decay enough in three or four months of summer weather to make the wood "doty" and brash and also discolor it, although it may not be "rotten" in the common sense of the term. Wood which has a moisture content below 18 per cent will not decay.

(f) *Insect Attack*.—Many woods, but especially hardwoods, are subject to insect attack when they are unseasoned. Open piling and other favorable drying conditions reduce the loss due to insect attack. The sapwood of ash, elm, hickory, oak, and a few other hardwoods is attacked by the powder-post beetle even when it is seasoned.

All of the above-mentioned injuries occur more commonly in summer than in winter. In fact, in cold weather, lumber does not need much attention before it is put into the kiln; although if it is not piled properly, it will not receive the beneficial effect of the slow drying which takes place in winter. In warm weather one must choose between two evils in caring for the lumber. If it is open piled, it is very apt to check and it may caseharden and honeycomb; whereas if it is close piled, it is more subject to stain and decay, and will not dry. It is nearly always better to have the lumber open piled in summer and take a chance on its checking and casehardening than it is to run the risks incidental to keeping the lumber piled without stickers or means of ventilation. Losses due to checking may be reduced appreciably by piling the lumber on stickers in an open shed or under rough cover.

128. Proper Methods of Piling Lumber in the Yard.—A lumber yard should be on open, dry, well-drained ground. Accumulations of decaying wood and dense growths of weeds around the piles should not be permitted. The foundations for each pile of lumber should be strong, durable, and properly aligned. Concrete, stone, or brick masonry makes the best piers on which to stack a pile of lumber. Creosoted posts and timbers also give good service; in the absence of these, a durable kind of wood may be used. If untreated wood is used, two coats of creosote should be applied wherever two pieces join or cross, or where the wood comes in contact with the ground. Non-durable woods and all sapwood, if not treated with a preservative, should not be included in the foundation because such material soon becomes infected with decay, which not only weakens the

foundations but also facilitates the spread of decay-producing fungi within the lumber pile. The foundation should be arranged so as to give the pile a slope of 1 inch per foot away from the alley. The lowest part of the pile should be at least 18 inches above the ground; no obstructions to the circulation of air under the piles should be permitted. Strong skids should be placed across the foundations at intervals corresponding to the spacing of the stickers. Steel I-beams or inverted railroad rails are excellent for this purpose. If wooden beams are used, it is advisable to place new, dry stickers on the skids before any lumber is piled on them, so as to retard the spread of any possible decay that may be in the skids.



FIG. 112.—A clean lumber yard in which the lumber is carefully piled and protected.

The lumber should be sorted out, if possible, so as to have each length in a separate pile. When it is necessary to put various lengths in the same pile, it is better to build up the ends of the pile square, as illustrated in Fig. 89, for kiln drying. Long pieces should never be put on top of short pieces, allowing the ends of the long pieces to overhang.

In placing the boards in each tier a space of about one-third of the width of the lumber should be left between the edges of the boards.

The stickers should be flush with the lumber at the ends of the pile, or they should protrude a little at the higher end.

Between the ends they should be placed at intervals ranging from 2 feet for thin lumber and kinds that warp easily to 4 or 6 feet for 1-inch and thicker stock if it does not warp easily. The stickers should be of uniform thickness and properly aligned in vertical series. The proper thickness of stickers ranges from $\frac{5}{8}$ to 2 inches, depending upon the seasoning requirements. Laths do not give sufficient spacing for lumber which is piled to season. The stickers may be a little wider than they are thick, especially for tall piles, but the practice of using stock boards wider than 3 or 4 inches for stickers is not recommended.



FIG. 113.—An obviously poor method of piling lumber.

It is advisable to construct a projecting roof over the pile so as to keep out the rain and snow and shade the ends. The spacing between the piles should not be less than 2 feet; 4 or 5 feet is preferable if conditions permit. Figures 112 and 113 are self-evident examples of good and bad practices in air seasoning.

129. Care of Lumber after Kiln Drying.—While the responsibility of the dry-kiln operator for looking after the condition of stock usually ceases when it is unloaded from the kiln, it should by no means be assumed that the moisture condition of the stock needs no further attention except possibly to keep the lumber under cover. On the contrary, lumber may be properly dried in a kiln and yet be entirely unsuited for a certain purpose when it

is worked up, just because it was not properly cared for after it was taken from the kiln. The dry-kiln foreman is often blamed for damage the stock received before it was put in the kiln and after it was taken out of the kiln. Therefore, he should make it his business, for self-protection, to know what care the stock receives outside of his official jurisdiction. In fact, it would be well to have a lumber superintendent at each wood-working plant whose business it is to see that the wood is kept under proper conditions from the time it arrives at the plant (or even from the time it is purchased) until the finished article, properly packed, is loaded for shipment. A factory might even extend its services by accompanying each high-grade, wooden product with instructions as to its proper care.

In all plants manufacturing high-grade woodwork, hygrometers should be used not only in the kiln to indicate the relative humidity there but also in the storage rooms, wood shop, finishing rooms, and warerooms, so that an actual knowledge of conditions may exist, and so that conditions may be changed if they are not suitable for the article which is being manufactured.

Assuming that the stock is properly kiln dried for a certain purpose, constant attention must be given to it to keep it in that condition if subsequent shrinking or swelling is a serious factor.

Lumber, as taken from the kiln, usually is not in the best condition for immediate use in the wood shop. In ordinary practice, the center of the pieces usually contains more moisture than the surface. This is shown in Sitka spruce in Table XII. On the other hand, if the lumber has been steamed at a high humidity at the end of the run and has not been properly redried, the surface may be wetter than the interior. Furthermore, some pieces may not be so dry as others.

In order to make the moisture content of the stock more uniform, and thereby reduce troubles in the shop and after manufacture, it is very desirable to allow the lumber to stand in bulk piles, if the average moisture content is approximately right, or on stickers, if the lumber is not fully dry, in the shop or in a storage room having the same temperature and humidity as the shop, for from three days to several weeks, the time depending upon the moisture distribution and the thickness of the lumber. During this time the moisture tends to become more uniform, and the stock is "acclimated" to shop conditions. If this equalization of moisture is not permitted before the lumber is cut up, it

will take place during and after manufacture. Any change in moisture in shaped pieces will cause a change in the dimensions of the piece and may cause warping, cupping, and checking.

It is very probable also that internal stresses due to ordinary shrinkage, or to casehardening, or to holding the lumber straight while drying may be partly relieved while in this temporary storage, although definite data, showing to what extent this is true, are lacking.

If properly kiln-dried stock is to be kept on hand for several months or indefinitely, it should be piled in bulk in a storage room which is so constructed that the humidity can be controlled within certain limits. In this way the proper moisture content of the lumber can be retained. For example, furniture stock should have a moisture content of about 6 per cent, and, according to the curves in Fig. 11, this requires a humidity of about 30 per cent. Spokes, rims, and hubs for wheels, which should have an average moisture content of 8 to 9 per cent, should be stored under 40 to 50 per cent humidity, whereas other parts of vehicles, as poles and bolsters, in which a little subsequent shrinkage is not harmful, need only be protected from the weather. It may not always be possible to keep the humidities so low as suggested for furniture stock, especially if the storage room is not heated. Slightly higher humidities may not be harmful, or even a considerably higher humidity for a short time.

Precautions such as keeping the doors and windows closed in damp weather, or slightly humidifying the air, if it is too dry, will help in preventing many of the troubles incident to wood-working shops. For more exacting lines of work it may be profitable to install air-conditioning apparatus in the storage room and shop. It is of prime importance in high-grade work in which excessive shrinking and swelling are objectionable to have the lumber at the proper moisture content when it is worked up.

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